Concurrent electromyography guided fMRI analysis to improve detection and reduce inter-session variability of the measured cortical response to ankle dorsiflexion

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Introduction: Functional Electrical Stimulation (FES) is a technique which can be used to elicit ankle dorsiflexion (ADF). It is used in rehabilitation to improve mobility in patients with multiple sclerosis and stroke. Here we assess the use of concurrent electromyography (EMG) in guiding fMRI analysis so as to improve the detection of activation due to active, passive [1] and electrical-stimulation (ES) induced ADF.

Method: Subjects (n=12) lay supine in the scanner with their foot strapped into a custom-made footrest and performed 20s of 0.4 Hz visually cued active, passive or ES-induced ADF, alternating with 20s rest for 10 repetitions. fMRI data were collected on a 3T Philips Achieva system. 32 contiguous transverse slices were acquired using T_2*-weighted echo-planar imaging (64x64 matrix, 3mm isotropic resolution, 40ms TE and SENSE factor 2). EMG data was concurrently recorded from the tibialis anterior at a sampling rate of 5000 Hz for each of the three ADF conditions using an MR-compatible amplifier (Brain Products, Munich, Germany).and processed using Brain Vision Analyzer. The EMG data were gradient-artefact corrected, high-pass filtered and rectified. To assess how the MRI environment impacted on the EMG signal, three subjects also performed ADF movements outside of the scanner and inside the scanner, both with and without EPI acquisition. To assess the inter-session reproducibility of the fMRI data, three of the subjects were scanned on three separate occasions for each ADF condition. fMRI data were corrected for physiological noise and analysed in SPM2. Data were modelled using: (A) conventional box-car analysis; (B) the convolution of the EMG signal with the canonical HRF [2]. A random effects group analysis was performed for each model (P<0.05 FWE corrected). For each subject scanned for the assessment of reproducibility, a coefficient of variation (CV), defined as the standard deviation of the signal change across sessions divided by the mean of the signal change across sessions, was calculated in primary motor cortex (M1), primary and secondary somatosensory cortex (SI and SII), and SMA for each type of ADF movement (Table 1).

Results: No significant difference in EMG responses was found between the three recording conditions (Fig. 1). The average EMG burst peak occurred at an earlier time for ES-induced ADF (Active 1.24 ± 0.8 s; Passive 1.4 ± 1.4 s; ES–induced 0.64 ± 0.2 s following the visual cue) and the mean amplitude was lower for passive ADF than active (p=0.03, paired T-test) and ES-induced ADF (p=0.0001, paired t-test). The ES-induced ADF produced the lowest CV score, indicating the reproducible nature of this task, with a slight improvement in CV when EMG-based analysis was used. Active ADF led to large CV values for analysis method (A) which were lowered (p = 0.003, all ROIs) using EMG-based analysis. The passive condition showed larger CV values for analysis (B) than (A), due to the low amplitude of the EMG signals during passive ADF. Figure 2 illustrates the similarity of the activation maps across sessions when EMG-guided analysis was used.

EMG-guided analysis significantly improved detection of activation for active (p =0.008) and ES (p=0.03) ADF as indicated by an increase in the total number of activated voxels count and higher T-scores on group analysis (Fig. 3). Figure 4 shows the group SPMs. Common activations are seen in contralateral primary somatomotor (S1/M1) and secondary somatosensory (SII) areas, bilateral insula, premotor (PM), cerebellum, SMA and cingulate motor areas (CMA). A significant increase in voxel count was found for active and ES-induced ADF compared to passive ADF in M1/S1, SII, SMA CMA, PM and cerebellum. Active ADF showed increased activation in SMA, PM, CMA, cerebellum compared to ES-induced ADF, and ES produced greater activation in bilateral SII and insula than active ADF.

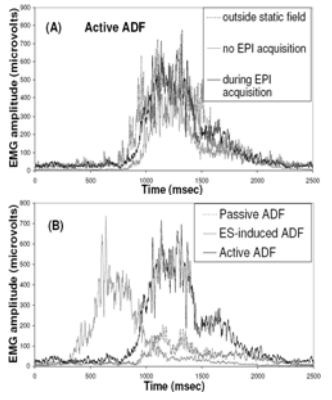

Fig 1: (A) Effects of fMRI environment on EMG response to active ADF (B) comparison of active, passive and ES EMG responses recorded during EPI.

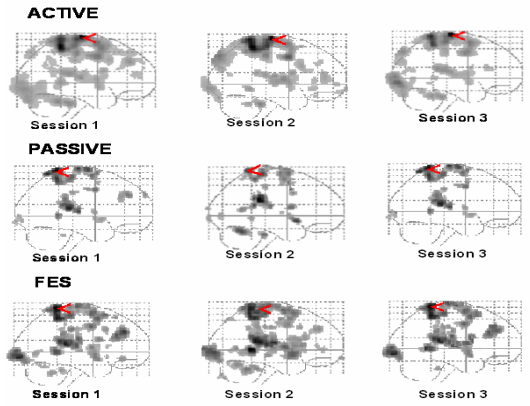

Fig 2: Reproducibility scans for the active, passive and ES-induced ADF movements for a single subject.

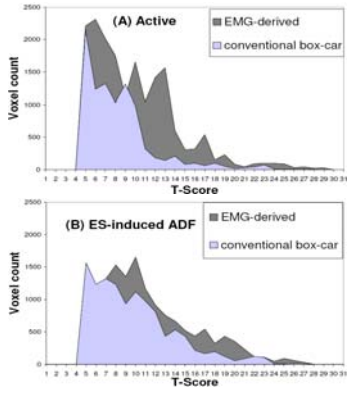

Fig 3: Histogram of T-scores for EMG-guided analysis and conventional box-car analysis for A) Active ADF and B) ES-induced ADF.

	ADF movement					
	Active		*Passive*		*ES-induced*	
	(A)	(B)	(A)	(B)	(A)	(B)
M1	19±3	10±2	15±3	33±3	12±3	7.1±0.7
S1	15±3	10±1	12±3	19±2	11±2	8.0±0.8
SMA	22±8	7.6±0.6	11±4	26±2	8±2	7±2
SII	23±3	17±3	20±3	21±3	7±1	7±2

Table 1: Mean ± SD of Coefficient of Variation, CV (%) for active, passive and ES-induced ADF using (A) a conventional box-car and (B) EMG derived analysis.

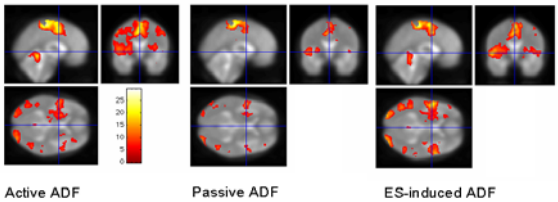

Fig 4: Group random effects contrasts for active, passive and ES-induced ADF (P<0.05 FWE corrected).

Conclusion: EMG-guided fMRI analysis improves the detection of activation and reduces inter-session variance for active and ES-induced ADF. A significantly larger number of activated voxels was found for active and ES-induced ADF compared to passive ADF. Active ADF produced greater activation in brain areas responsible for motor planning, execution and visuomotor co-ordination compared to ES-induced ADF, whilst the ES-induced activation was greater in bilateral SII and insula than for active ADF. This is hypothesised to result from increased sensory integration. The improved methodology used in this study serves as a proof of feasibility for the use of fMRI in the assessment of the cortical response to ADF movements following a longitudinal course of FES therapy in patients with MS and stroke.

References: (1). Ciccarelli, O., et al., Exp Brain Res 166, 31-42, 2005 (2). van Rootselaar, A.F., et al., Hum Brain Mapp, 28, 1117-27, 2007.