Neuropsychophysiological mapping: Concurrent psychophysiological recording and fMRI at 7T

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BACKGROUND

Background. In this study, we examine the effects of internal and external focus of attention during a hand-grip task under two contexts: social pressure, and no pressure. This is the first study of its kind to combine measures of peripheral (e.g., psychophysiological measurements) and central nervous system (functional magnetic resonance imaging [fMRI]) activity. Here, we present initial findings of multichannel psychophysiological data collection during submillimeter 7T fMRI.

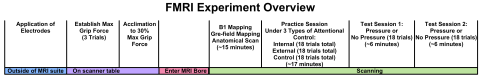
METHODS

Data were acquired in twelve adults using BIOPAC MRI-compatible modules, leads, and electrodes. FMRI scanning was performed on a 7T Siemens MAGNETOM. Electrocardiograph (ECG), respiration, electrodermal activity (EDA), electromyogram (EMG), and grip force were collected during simultaneous high-resolution fMRI.

FMRI was carried out using an echo-planar sequence consisting of 37 slices acquired parallel to the AC-PC line (0.85mmx0.85mmx1.5mm voxels, TR/TE: 3000/28ms, 70° flip angle, base/phase resolution 234/100, interleaved sequence).

FMRI Task. Participants were asked to complete a hand-gripping task under two testing conditions: once with social pressure, and once without any pressure. Testing sessions were counterbalanced across individuals.

FMRI Experiment Overview

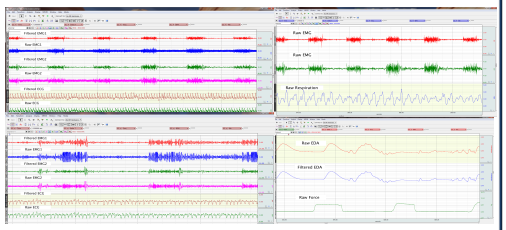


Each block (i.e., internal, external, or control) consisted of 6 trials. Each trial consisted of a 6s squeeze followed by a 9s rest. Blocks were repeated 3 times within the practice session. An addition 9s of rest occured between blocks.

For Test Sessions, participants completed three blocks of trials (6 trials per block). Trials consisted of a 6s squeeze, followed by a 9s rest period. An addition 9s of rest occured between blocks.

Psychophysiology Preprocessing. EMG, EDA, and basic cardiovascular measures were derived after signal processing to remove scanning artifacts. EMG and EDA signals were reliably extracted and minimally affected by the simultaneous acquisition. For EMG data, a comb-band stop filter (12.33Hz and up to the Nyquist frequency) was applied. EDA data were subjected to a 10 Hz IIR low-pass filter to remove artifacts. Respiratory signals were largely unaffected. ECG signals were more vulnerable to scanning parameters, and highly distorted due to magnetohydrodynamic artifacts, thus a less automatic processing method was employed.

Effects of Filtering



FMRI PROCESSING

Data were processed using FSL (http://fsl.fmrib.ox.ac.uk/fsl/fslwiki/). Standard preprocessing steps were completed including brain extraction, Gaussian smoothing (5mm FWHM), and slice timing correction. Data were also motion corrected, with outliers removed from subsequent GLM analyses (generated from fsl_motion_outliers). Regressors of interest were extracted physiological timecourses corresponding to the TRs. These included ECG, EDA, 2 channels of EMG (extensor and flexor muscles), and respiration. Force data were also included in the analyses. Group analyses were performed, controlling for within-subjects effects. Data were thresholded at cluster and voxel FDR-corrected p<0.05.

RESULTS

FMRI Differences in Motor Control. Differences between the pressure and no pressure condition emerged for contrasts examining Squeeze > Rest Following Squeeze, and also for Rest Following Squeeze > Rest at the End of the Session. In both cases, the pressure condition elicited greater activation. For the Squeeze > Rest Following Squeeze, the pressure condition elicited greater activation throughout the parietal lobe, potentially suggesting a hypervigilance to sensory-motor integration (Table 1, Figure 1). Comparing different rest conditions (i.e., rest that immediately followed a motor trial versus rest at the end of the experiment), the pressure condition demonstrated greater activation throughout the brain, including regions involved in premotor planning (BA 6/8), decision making (BA 32), and somatosensory processing (BA 7/40) (Table 2, Figure 2).

FMRI Differences in Neuropsychophysiological Correlates. The only psychophysiological measurement that demonstrated differences in neural correlates between the pressure and no pressure condition was force. For force, the no pressure condition elicited greater activity throughout the parietal lobe, as well as in key subcortical structures such as the thalamus (Table 3). Because we did not find significant group differences, we collapsed across the two conditions, to look for consistent neural correlates of psychophysiological variables. Using this approach, two psychophysiological regressors demonstrated significant group effects: EMG corresponding to the flexor muscles and ECG (Tables 4/5, Figures 3/4, respectively).

Behavioral Performance. Participants made more errors in attempting to reach their target force (30% of max) during the pressure condition, compared to the no pressure condition (t (10) = 2.255, p < 0.05). Thus, we found support for "choking under pressure", or stress.

TABLE 1
Squeeze > Rest immediately following squeeze trial
No Pressure < Pressure

Lobe	x	y	z	Description	BA
Parietal	28	-65	31	Right Precuneus	7
	32	-64	47	Right Superior Parietal Lobule	7
	37	-64	44		
	26	-61	53		
	32	-69	38	Right Precuneus	19
	33	-60	41	Right Inferior Parietal Lobule	39
Sub-lobar	40	-23	10	Right Insula	13
	40	-19	5		
	36	-5	13		
	29	9	11	Right Claustrum	
	28	2	18		
	34	-13	7		

TABLE 2
Rest following squeeze trial > Rest following experiment
No Pressure < Pressure

Lobe	x	y	z	Description	BA
Frontal	-35	-18	60	Left Precentral Gyrus	4
	-20	-6	63	Left Middle Frontal Gyrus	6
	9	-6	62	Right Medial Frontal Gyrus	6
	17	6	61		
	6	0	62		
	13	7	54		
	15	-3	58	Right Middle Frontal Gyrus	6
	28	18	51		
	17	0	64	Right Superior Frontal Gyrus	6
	25	23	36	Right Middle Frontal Gyrus	8
	28	23	39		
	34	18	48		
	24	22	48	Right Superior Frontal Gyrus	8
	-33	24	29	Left Middle Frontal Gyrus	9
	-49	18	34		
	-42	15	27		
	-38	29	35		
	8	16	37	Right Cingulate Gyrus	32
	-46	19	25	Left Middle Frontal Gyrus	46
	-46	18	20		
Parietal	-4	-55	44	Left Precuneus	7
	-13	-44	52		
	-9	-59	36		
	-43	-35	54	Left Postcentral Gyrus	40

All coordinates in Talairach space

FIGURE 1

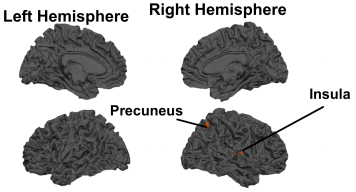


FIGURE 2

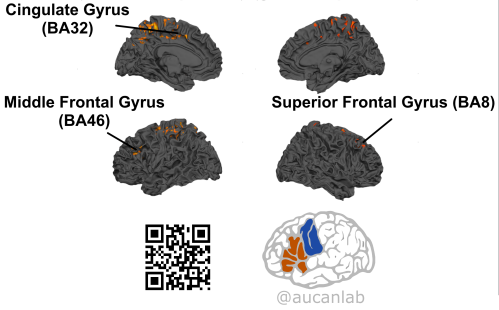


FIGURE 3

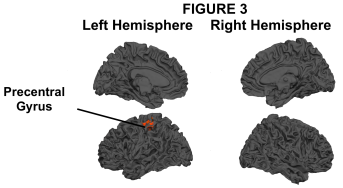


FIGURE 4

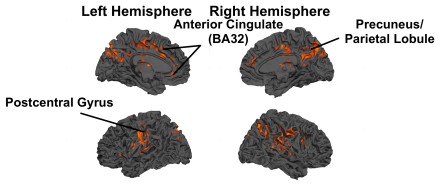


TABLE 3
Neural Correlates of Force
No Pressure > Pressure

Lobe	x	y	z	Description	BA
Parietal	39	-64	44	Right Inferior Parietal Lobule	7
	28	-65	35	Right Precuneus	7
	26	-61	53	Right Superior Parietal Lobule	7
	32	-64	47		
	32	-69	38	Right Precuneus	19
	30	-76	30		
	-48	-44	37	Left Inferior Parietal Lobule	40
	-39	-41	38		
	-33	-52	42		
	-52	-43	43		
	-37	-57	47		
	-48	-39	38	Left Supramarginal Gyrus	40
Sub-lobar	41	-11	18	Right Insula	13
	32	-24	22		
	45	-14	13		
	36	-19	23	Right Thalamus	
	25	-22	15		
	17	-18	-14		

TABLE 4
Neural Correlates of EMG (Flexor Carpi Radialis)
Collapsed across testing conditions

Lobe	x	y	z	Description	BA
Frontal	-29	-30	44	Left Precentral Gyrus	4
	-33	-18	58		
Parietal	-33	-35	62	Left Postcentral Gyrus	2
	-39	-37	58		
	-28	-37	58		5
	-35	-40	52	Left Inferior Parietal Lobule	40

TABLE 5
Neural Correlates of ECG
Collapsed across testing conditions

Lobe	x	y	z	Description	BA
Frontal	38	5	56		
	49	7	37	Right Inferior Frontal Gyrus	9
	28	-65	35		
	41	11	32		
	-12	10	36	Left Cingulate Gyrus	32
	-14	11	47	Left Medial Frontal Gyrus	32
	52	5	46	Right Inferior Frontal Gyrus	44
	47	14	19		45
Limbic	2	28	37	Right Cingulate Gyrus	23
	-3	36	8		
	-12	32	3	Left Anterior Cingulate	24
	-11	2	42		
	11	12	32		
	10	-17	42	Right Cingulate Gyrus	24
	-7	-19	46	Left Cingulate Gyrus	31
	-18	-30	43		
	8	-37	39	Right Cingulate Gyrus	31
	1	34	20	Left Anterior Cingulate	32
	1	37	28	Right Anterior Cingulate	32
Occipital	-13	-81	38		
	7	-81	35	Right Cuneus	18
	11	-83	31		19
Parietal	9	-64	29	Left Precuneus	31
	-4	-71	43	Right Precuneus	7
	28	-68	46		
	48	-74	45	Right Superior Parietal Lobule	7
	44	-59	50		
	45	-60	37	Right Angular Gyrus	39
	37	-63	37	Right Precuneus	39
	-59	-16	20	Left Postcentral Gyrus	43
Sub-lobar	-29	21	4		
	-27	-18	11	Left Claustrum	
	-27	-23	7		
	-16	1	6	Left Lentiform Nucleus: Lateral Globus Pallidus	
	-12	6	1		
	21	3	3	Left Putamen: Lentiform Nucleus	
	-23	-21	9	Left Thalamus	
	14	5	14	Right Caudate Body	
	16	-11	23		
	28	-13	20	Right Claustrum	
	21	-1	19	Right Putamen: Lentiform Nucleus	
Temporal	49	-35	16	Right Superior Temporal Gyrus	39

CONCLUSIONS

We successfully collected submillimeter fMRI and multichannel psychophysiological data in an ultra-high field MR environment. Such data collection provides insight into the dynamic interactions of the central and autonomic nervous systems.

In the context of the present experiment, we found neurophysiological differences between the pressure and no pressure conditions, such that the pressure condition elicited greater activation during the motor task compared to the rest period immediately following it. Additionally, we found that the pressure condition elicited greater activation throughout the brain following each motor trial, suggesting that during the pressure condition, participants were using regions of the brain known to be involved in cognitive processing. These data suggest that participants may have been thinking more about their performance, and lend insight into potential neural networks that may be involved in the choking under pressure phenomenon.

Relationships between central and peripheral neurophysiological measures did not change between conditions. Collapsing across conditions, we found consistent neural correlates for ECG/EMG, but not for respiration/EDA. This may be due to lack of power, or variable neural correlates for these signals.