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Research paper

Neural Activation Patterns During Emotional Working Memory Task: an fMRI Study

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Abstract

Emotional stimuli may have positive effects in cognitive processes that allows for temporary storage and manipulation of information. However, the influence of emotional stimuli, along with its neural correlates have not been fully analysed so far. This study aimed at investigating the neural and behavioral effect that the emotional content of stimuli has on working memory performance. In this functional magnetic resonance imaging (fMRI) study, we induced different emotional faces pictures while participants (n = 17) performed an n-back visual working memory task. Data were analyzed using Statistical Parametric Mapping 12 (SPM-12). Result showed emotional working memory n-back tasks activated motor, occipital, frontal, parietal regions. Frontal and parietal regions showed more activation in 1-back task association with increased working memory load. This showed that additional component need in maintaining a representation of the previous stimuli.

Keywords: *Functional Magnetic Resonance Imaging; n-back; working memory; emotional working memory*

1. Introduction

Emotional working memory (EWM) refers to short-term memory functions that are involved in encoding, maintaining, manipulating and retrieving affective information; it can also be defined as the ability to identify, understand and regulate emotions. Emotional faces are typically more likely to be remembered than non-emotional information. Experimental studies on emotion have shown that particular qualities of pictures can elicit an emotional response that varies according to the valence (positive and negative) and the level of arousal (from neutral to exciting) of the stimuli [1]. Furthermore, the effects of emotion can produce both memory enhancement and memory inhibition depending on the level of arousal of an emotional state.

The ability to manipulate valence information in working memory is thus a critical component of emotion regulation processes. For example negative and positive stimuli elaboration may be attenuated or amplified such that it may increase or decrease people's vulnerability to mood disorders. Numerous works have found an interaction between amygdala and orbitofrontal cortex which plays a crucial role in attributing emotional qualities to stimuli. This information is subsequently maintained and manipulated in the dorsolateral prefrontal cortex [2].

Previous research showed that declarative memory for emotional stimuli is better than memory for neutral stimuli in both healthy young adults and older adults. Although older adults generally have poorer memory than young adults, both age groups remember more about emotional information, such that the overall age discrepancy in memory is less pronounced for highly arousing events. In other words, studies suggest a preserved memory advantage for emotional stimuli in older adults with healthy cognitive aging [3]. It has been found that patients remembered negative targets significantly better than neutral and positive targets, in contrast to the results found in healthy older adults for emotional stimuli in patients with mild cognitive impairment [4]. Patients with chronic depression reported increased arousal to negative emotional expressions [5]. They also showed an increase in left amygdala reactivity during implicit processing of emotional expressions following psychotherapy.

A variety of experimental paradigms to measure working memory (WM) have been used to study diverse populations; some examples include the Digit Span task, the Sternberg task, the n-back task and delayed match-to-sample. The n-back task is, however, likely the most a popular measure of WM used in fMRI studies. Across studies, many different types of stimuli have been used via various input modalities (visual including spatial, auditory, and olfactory) making demands on different processing systems. In this study, an fMRI experiment of WM in healthy adults was conducted that used a simple visual WM paradigm n-back to probe the effects of difficulty of the task on brain activations. It was done with the two levels of difficulty (0-back to 1-back) with facial expressions as stimuli. In terms of cognitive requirements, both tasks require the goal of each task to be kept in mind, scanning the visual display, identifying the target and making a motor response.

Previous research stated that subjects capture emotional stimuli first compared to other distracters [6]. Different emotional faces stimulus can yield a different specific neural activation. Emotional working memory can be efficient when emotional task is given to the subjects where brain tends to capture negative emotional better than neutral or positive emotions [2,7]. In addition, a study [8] has proved that neural response to facial expression were acquired even though there were no emotion task involved during scanning time (eg: judging gender). This proves that emotions were automatically processed without selective attention.

In this study, participants were presented with a series of stimuli and are asked to indicate whether the current stimuli matched the stimuli presented n stimuli back in the series. The task requires online monitoring, updating, and manipulation of remembered information and is therefore assumed to place great demands on a number of key processes within WM [9]. The objective of this study is to compare regional activation across 0-back and 1-back task by using facial expressions as stimuli. Our hypothesis 1-back should be more cognitive taxing than the 0-back task and thus should exhibit a greater developmental trend.

2. Methodology

The study was approved by the Research Ethic Committee of Universiti Kebangsaan Malaysia (ethic no: FF-2014-232). A total of 17 healthy individuals (age range = 20 – 50 years, 7 female). The mean age was 31.12 years. All participants reported no history of neurological, medical or psychiatric disorders and free of MRI contraindications. Written informed consent was obtained from all participants. Those eligible were invited to take part in the fmri study. They completed the Quick Inventory Depressive Symptomatology [10] and Mood Disorder Questionnaire [11]. The fmri session was done in Radiology Department, Hospital Canselor Tuanku Muhriz. The scan of brain activation was done in supine position with eyes closed and while doing working memory task. Participants with excessive motion, poor image quality or artifact and missing scans or functional data were excluded from imaging data analyses.

2.1. Stimuli

A total of 16 faces were selected including happy, angry, fearful, sad, and neutral faces each from 4 different individual actors (2 males). Faces were rescaled and covered with an oval frame to mask individual characteristics [12]. Stimuli were presented using E-Prime 2.0 software (Psychological Software Tools, Pittsburgh, Pennsylvania). N-back Task. Participants performed an emotional faces processing WM task with two conditions. This task is most typically known as the n-back and the conditions presented were 0-back and 1-back using block-design paradigm was used (Figure 1) to isolate activation related to the task effect as much as possible. Instructions and a short practice were given outside the scanner prior to scanning; instructions also repeated verbally to the participant at the beginning of each run through the intercom. Participants were instructed to respond whenever the current stimulus was the same as the one presented n positions back in the sequence (n depending on the load level, that is, 0 or 1).
Stimuli consisted of facial expressions varies and were projected using an active video projector and presented on a screen at the foot of the scanner bed, viewed through a mirror placed above the participant's head. Participants were instructed to respond as quickly and accurately as possible. They were asked to press a specified hand grip button with their left thumb for targets consistent and another button with their right thumb for targets that is inconsistent. For n = 0 (0-back), the target was any facial expression that matched a pre-specified facial expression. For n = 1 (1-back), the target was any facial expression that matched to the facial expression immediately preceding it. There were four runs within the block. Each run consisting of a 0-back and 1-back load level with identity or emotional faces expressions in random order which lasted 4 minutes 26 seconds each.

2.2. MRI Procedures & Acquisition

All MR images were collected on a MRI 3.0 Tesla Siemens Magnetom Verio system. A set of high-resolution T1-weighted whole-brain SPGR images was acquired using an axial fast spoiled gradient recalled (SPGR) sequence (TE/TR/flip angle = 2.35ms/6ms/9°, 156 slices, voxel size = 1×115 mm2) as an anatomical reference prior to the acquisition of functional images. Image were acquire using a T2*-weighted gradient echo planar imaging (EPI) sequence, sensitive to blood oxygen level-dependent (BOLD) contrast functional images during the visual memory paradigm (TR/TE/flip angle = 2000ms/30ms/90°, voxel size = 3.8×3.8×3.4 mm3, 31 axial slices). A radio-frequency receive-transmit transverse electromagnetic head coil was used. Head movement was limited by foam padding within the head coil.

2.3. fMRI Data Analysis

Functional imaging data were preprocessed using Statistical Parametric Mapping 12 software implemented through MATLAB (Mathworks Inc., Natick, MA). The images of each run underwent a slice timing procedure to correct for slice sequence. The images were re-aligned with the first image for motion correction and co-registered with high- resolution structural images. The images were then spatially normalized and resliced to the MNI standard template (Montreal Neurological Institute). The images were spatially smoothed by convolution with a three-dimensional Gaussian kernel (FWHM = 6mm).
Second level analysis using paired t-test was used to examine task difficulty differences between 0-back and 1-back emotional working memory. One sample t-test was conducted for the individual effects of contrast. Brain regions were identified using MNI coordinates and the Automated Anatomic Labelling (AAL) atlas [13] as implemented in the WFU PickAtlas (School of Medicine, WinstonSalem, NC). The result is visualized using xjView toolbox (http://www.alivelearn.net/xjview).

3. Result

3.1. Behavioural Result

The number of correct responses and reaction times were calculated for each participant in the two conditions (1- back, 0-back) for emotion identification task. The mean reaction times were shortest and mean percentage of correct responses was highest in 0-back tasks (Fig. 1). However, there were no significant differences in accuracy (p=0.6112) and correct responses (p =0.2069).

3.2. Cortical Activations

The data were initially treated to a whole-brain cluster analysis for 0-back (EM0B) (Fig.2) and 1-back emotional (EM1B) (Fig 3.) working memory. The objective was to examine emotional working memory activation in contrast images (1-back and 0-back). The statistical images were assessed for cluster-wise significance using a cluster-defining threshold of P = 0.001 (extend threshold), and 0.05 FWE-corrected at cluster size (volume = 41648 voxels; smoothness [FWHM in mm] = 12.3, 12.8, 11.3; RESELS = 545.1).

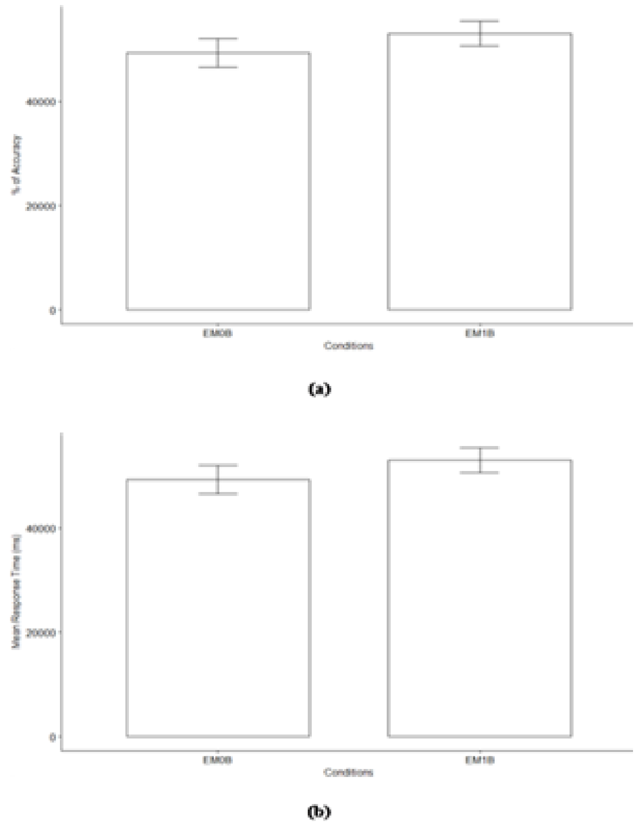

Fig. 1: Response accuracy (% correct; error bars demonstrate standard error of the mean); (a) and response latency (in ms; error bars demonstrate standard error of the mean for 0-back (EM0B) and 1-back (EM1B) task conditions.

Specifically, in the 0-back task regions of significant BOLD activation were the Right Middle Occipital, Left Rolandic Operculum, Left SupraMarginal, Left Inferior Parietal and Left Supplementary

Motor Area; in the 1-back task, right Cerebelum Crus1 , bilateral Fusiform gyrus, Right Inferior Occipital, Right Inferior Temporal, Left Insula, Left Inferior Frontal Tri, Left Rolandic Operculum, Left Inferior Frontal Operculum, Left Precentral and bilateral Supp_Motor_Area were activated (Table 1).

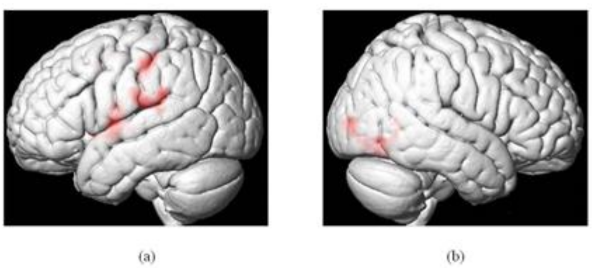

Fig. 2: Brain activation in (a) left (b) right hemisphere for EM0B 0 vs baseline contrasts are shown superimposed on the average structural image.

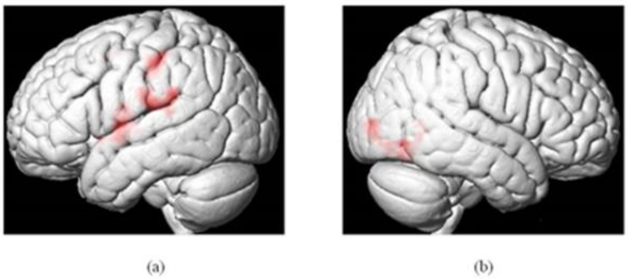

Fig. 3: Brain activation in (a) left (b) right hemisphere for EM1B vs baseline contrasts are shown superimposed on the average structural image.

Table 1: Significant activation clusters (P < 0.05, FWE-corrected at cluster level) revealed by the contrast of 0-back and 1-back emotional working memory

Activation Cluster	Cluster extent (voxels)	Maximum T-value	Peak MNI coordinates		
			x	y	z
EWM0B vs baseline					
Occipital_Mid_R	129	6.43	30	-91	5
Rolandic_Oper_L	159	7.90	-39	-4	14
SupraMarginal_L	141	7.44	-48	-34	26
Parietal_Inf_L	70	7.13	-48	-25	47
Supp_Motor_Area_L	61	6.08	-9	-4	56
EWM1B vs baseline					
Cerebelum_Crus1_R	40	6.99	36	-52	-31
Fusiform_L	90	8.62	-39	-70	-16
Fusiform_R	73	10.0	42	-46	-22
Occipital_Inf_R	77	7.83	42	-67	-13
Temporal_Inf_R	125	7.75	48	-61	-10
Insula_L	216	9.57	-30	20	5
Frontal_Inf_Tri_L	29	6.58	-42	20	-1
Rolandic_Oper_L	51	8.04	-45	-4	8
Frontal_Inf_Oper_L	120	7.85	-48	11	-1
Precentral_L	199	7.37	-33	-1	56
Supp_Motor_Area_L	141	10.50	-6	11	53
Supp_Motor_Area_R	81	7.86	12	8	53
EWM0B vs baseline					
Occipital_Mid_R	129	6.43	30	-91	5

In comparisons of brain regions' activated changes between the 0-back and 1-back, a paired t-test revealed significant difference. The statistical threshold was set at cluster-defining threshold of P = 0.001 (extend threshold), and 0.05 FWE-corrected at cluster size (volume = 41648 voxels; smoothness [FWHM in mm] = 11.8, 12.1, 10.7; RESELS = 633.8). Specifically, the 1-back task resulted in greater activation of Left Fusiform, Right Inferior Occipital, Left Middle Occipital, Left Middle Frontal, Right Inferior Frontal, Left Inferior Parietal, Right Middle Frontal and Left Supplementary Motor Area (Table 2). This analysis indicated that 1-back significantly increased some regions of brain activities for working memory.

Table 2: Significant activation clusters (P < 0.05, FWE-corrected at cluster level) revealed by the differences between contrast of 0-back and 1-back emotional working memory

Activation Cluster	Cluster extent (voxels)	Maximum T-value	Peak MNI coordinates		
			x	y	z
0-back vs 1-back					
Rolandic_Oper_R	90	7.32	60	-7	8
Rolandic_Oper_L	82	5.29	45	-13	11
Precuneus_L	136	8.90	12	-55	14
Cingulum_Ant_L	63	5.14	6	50	11
Cingulum_Mid_L	134	5.92	9	-37	41
1-back vs 0 back					
Fusiform_L	173	7.37	42	-46	-22
Occipital_Inf_R	177	6.24	39	-67	-13
Occipital_Mid_L	90	6.89	21	-97	5
Frontal_Mid_L	208	8.17	30	-1	50
Frontal_Inf_Oper_R	93	6.65	39	14	26
Parietal_Inf_L	70	6.28	45	-40	44
Frontal_Mid_R	44	6.30	33	2	56
Supp_Motor_Area_L	76	7.73	3	8	50

4. Discussion

Visual WM is the cognitive mechanism that encodes, maintains, manipulates, and retrieves visual and spatial information over the short-term. WM has been investigated extensively in adults revealing the importance of the frontal and parietal lobe regions in the mature brain. The main goal of this study was to investigate the changes in neural correlates during an emotional-monitoring N-back task by using emotional faces. Studies show that the middle and frontal gyrus, prefrontal cortex, premotor areas, supplementary motor area, anterior cingulate cortex and parietal areas are activated by the n-back task. In addition, previous studies have found an interaction between amygdala and orbitofrontal cortex which plays a crucial role in emotional working memory with prefrontal cortex play a role in maintained and manipulated the information [14].

Our study agrees with these results showing activity in the fusiform gyrus, inferior frontal gyrus, supplementary motor area, rolandic operculum, parietal lobe and cingulate cortex which related in working memory task. Fusiform in the temporal lobe thought to be important in facial recognition, color processing, and word recognition. Previous work [15] has proved that fusiform face area is very sensitive to both stimulus either face stimuli or face part and may yield different result between subjects.

Previous neuroimaging studies demonstrated that neural substrates sub serving WM has primarily been associated with activation in frontal and parietal cortices with particular focus on the prefrontal cortex (PFC). It has also been suggested that activity in the frontal regions may be load-dependent, for example activation is related to the amount of information that has to be memorized or increased WM load [16].

The inferior parietal lobule has been described as a buffer and thought to be involved in storage of working memory contents. In this study, more regions activated in 1-back task compared to 0-back task especially in parietal and frontal regions. These observations were in agreement with previous work related in n-back working memory.

However, anterior cingulated gyrus which often described in relation to increased effort, complexity, or attention did not survive the threshold. Based on the behavioural result, participants able to answer both conditions without any difficulty this may be related to less complexity of the tasks. Contrary to the research findings there are no activations in amygdala reactivity in both conditions. Amygdala is a brain structure that directly mediates aspects of emotional learning and facilitates memory operations especially fear related emotions and memories [4, 17]. However in this study, differences between emotions (sad, happy, fear, neutral) are not within the scope of this article.

5. Conclusion

These data add to the current knowledge on the brain activity toward emotional working memory using faces stimuli, in which increase number of regions are association with increased working memory load.

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