DOI: 10.14744/DAJPNS.2020.00106
Dusunen Adam The Journal of Psychiatry and
Neurological Sciences 2020;33:376-387

RESEARCH ARTICLE

Remembered or forgotten stimuli: a functional magnetic resonance imaging study on the effects of emotion

Erol Ozcelik[1], Betul Kilic[2]

[1]Cankaya University, Faculty of Arts and Sciences, Department of Psychology, Ankara - Turkey
[2]Middle East Technical University, Faculty of Arts and Sciences, Department of Psychology, Ankara - Turkey

ABSTRACT

Objective: The first aim of this study is to examine why emotional events enhance memory for preceding stimuli. The second goal is to identify brain regions associated with remembering and forgetting by finding brain activation differences during encoding of remembered and forgotten stimuli. The third goal is to examine which brain areas are activated when studying emotional pictures compared to neutral ones.

Method: In each trial, a picture of an object followed by an emotional or neutral picture from the Turkish culture were presented to 15 volunteers. The effect of the succeeding pictures on the remembering of preceding stimuli was examined. The participants studied the stimuli in the magnetic resonance scanner and, meanwhile, brain images were taken. The memory performances of the participants were measured with the recognition test administered one week later.

Results: Behavioral results suggest that emotion has no effect on memory for preceding stimuli. Functional magnetic resonance imaging results indicate that remembered stimuli compared to forgotten ones caused more activation in left inferior frontal gyrus and left superior medial gyrus. Emotional pictures create more activation in the - mid-temporal gyrus and supramarginal gyrus compared to neutral images.

Conclusion: Brain structures in which activations are observed in remembered stimuli compared to forgotten ones (left inferior frontal gyrus and left superior medial gyrus) are responsible for the semantic elaboration and associative memory formation. Thus, it can be concluded that object pictures are remembered because they are processed more deeply. Besides, activations are observed in the areas known to be related to the processing of emotional face expressions when emotional and neutral pictures are compared.

Keywords: Emotion, fMRI, memory

INTRODUCTION

An emotional event, such as a terrible traffic accident, is remembered much better than a neutral event (1). From an evolutionary perspective, remembering information around emotional events is essential for survival and for passing on genes to the next generation (2). In one of the key researches in the field, it has been revealed that presenting emotional pictures 4 seconds after neutral stimuli increase the remembering of neutral stimuli compared to presenting neutral pictures (3). Of interest to researchers here is that emotional events

How to cite this article: Ozcelik E, Kilic B. Remembered or forgotten stimuli: a functional magnetic resonance imaging study on the effects of emotion. Dusunen Adam The Journal of Psychiatry and Neurological Sciences 2020;33:376-387.

Correspondence: Erol Ozcelik, Cankaya University, Faculty of Arts and Sciences, Department of Psychology, Ankara - Turkey
E-mail: ozcelik@cankaya.edu.tr

Received: March 20, 2020; **Revised:** July 14, 2020; **Accepted:** September 28, 2020

automatically affects the remembering of pre-presented neutral stimuli that are not presented. However, no studies have been carried out to explain why this effect occurs. The brain, once described as a black box, began to be directly observed using advanced techniques such as functional magnetic resonance imaging (fMRI) applied in the field of neuroscience. In this context, this study aims to examine why emotional events increase the remembering of neutral stimuli, which are just presented before them, using the fMRI technique. This advanced imaging method can reveal the brain areas responsible for the enhancement of observed memory performance. Since the relationship between brain structures related to this process and other cognitive processes have been described in the literature, arguments can be developed about the cognitive processes that cause an increase in memory performance.

Valence and Arousal

One of the interesting topics in the literature is that emotional stimuli are remembered more than neutral ones. In emotional memory studies, emotional stimuli are generally examined in two dimensions as valence and arousal (4). Valence determines how positive or negative the stimulus is emotionally, and arousal determines the degree of calmness or excitement in the person (4). Valence and arousal independently increase the remembering of stimuli and trigger different activation in the brain (5). At this point, the valence and arousal properties of emotional stimuli are one of the important issues that need to be investigated.

Remembering Emotional Events

Research and practice in both cognitive and clinical psychology show that emotional events are better remembered than ordinary events. Similar results were obtained when different stimuli such as words, sentences, and pictures were used (6,7). Stimulants with positive or negative valence are also remembered better than neutral ones (8). As a result of researches carried out on various cognitive processes of emotions using brain imaging techniques, it has been found that medial temporal lobe (MTL) regions, prefrontal cortex, and various brain structures, especially the amygdala, are involved in these processes (4). Researches show that the amygdala occupies a central place in the emotional memory system and plays a role in the activation of other parts of the brain associated with emotional memory (modulator effect) (9). It is observed that the emotional memory performance of patients with bilateral amygdala damage (Urbach–Wiethe syndrome) is decreased (10). In addition, lesion studies conducted with patients with damaged MTL emphasize that reciprocal connections between the amygdala and MTL regions play a critical role in emotional memory processes. Another factor in the better remembering of emotional stimuli is the consolidation process, which makes memory traces stronger over time and become more resistant to interference. While there was no difference in memory tests applied immediately in Urbach–Wiethe patients with amygdala damage compared to normal participants, a loss in memory performance was observed when the memory test was administered late (for example, 1 week after the study) (11). In addition to this study, considering the lesion studies showing that the hippocampus is effective in the consolidation process (12), it can be argued that the amygdala affects the consolidation processes by modulating the hippocampus (13).

Dm Effect

Research in the literature showing that emotional stimuli are remembered better than neutral ones has increased the interest in the causes of this effect (14). There are many reasons why emotional events are better remembered. Among the researches on this subject, those examining the Dm effect (difference due to memory effect or subsequent memory effect) stand out (15). The Dm effect is defined as the differences in neural activation between remembered and forgotten stimuli in the post-experiment process (16). Event-related neuroimaging techniques, especially fMRI and event-related potentials, enable detailed studies of the Dm effect. In this case, by looking at the differences in neural activation of remembered and forgotten stimuli during encoding, the reasons for better remembering of emotional stimuli can be investigated using brain imaging techniques. Although there is not enough research on this subject in the literature, studies on the Dm effect using words or pictures via various brain imaging techniques, especially with event-related fMRI, draw attention. It has been found that activation in the frontal and MTL predicts the Dm effect in some studies using emotional and neutral stimuli (17).

The Effect of Emotional Events on Remembering the Preceding Stimuli

In addition to better remembering of emotional events, one of the leading research in the field (3) found that emotional events increase the remembering of preceding stimuli. The point that draws the attention of researchers here; emotion automatically affects the remembering of preceding neutral stimuli that are not presented. In this study, pictures with positive or negative emotions were presented 4 or 9 seconds following the neutral stimuli. Participants assessed the intensity of emotional pictures and remembering of neutral stimuli by scoring. One week later, the volunteers were presented with neutral stimuli and asked which ones they were working on. Unexpectedly, it was found that the memory performance associated with neutral stimuli shown 4 seconds before the emotional pictures were affected by the emotional intensity of the pictures, while the memory performance associated with the neutral stimuli shown 9 seconds before was not affected by emotional events. In the second experiment, unconventional neutral pictures were presented instead of emotional pictures, and the effect found in the previous experiment was not observed. With the second experiment, it was shown that better remembering of stimuli is due to the emotional nature of the events, not the distinctive characteristics of the events.

Similar to the findings of Anderson et al. (3), it was found in a very recent study that emotional stimuli increase the remembering of stimuli related to task goals (18). In an experiment during which each picture was displayed for 100 milliseconds, one of the 12 pictures presented was rotated 90 degrees to the right or left (19). In this experiment where stimuli were presented very quickly, the task of the participants was to find out which direction the critical picture was rotated. It was observed that when a negative emotional picture was presented with 2 stimuli before the critical pictures, the direction of the rotation was better detected than a neutral picture. These results were interpreted as emotional events strengthened the consolidation process of critical pictures. These two studies show that emotional events increase the remembering of preceding stimuli compared to neutral events, but the reason for this effect is unknown.

The reason emotional events increase the remembering of preceding stimuli may also be due to mechanisms other than consolidation processes. Finn and Roediger (20) argued that the cause stemmed from the reconsolidation processes that occur during the return of memory traces. However, Dunsmoor et al. (21) claimed that information that could be associated with emotional events was better remembered. Mather et al. (22) argued that emotional events increased the priority of information around and thus elevated memory performance in a model where stimuli competed for limited mental resources. Similarly, it was observed that the more important the stimuli were perceived, the more it was remembered. (23) Schmidt and Schmidt (24) suggested that the responsible mechanism was the attention directed to emotional information.

In light of the findings in the literature, the hypotheses of this study are as follows:

Hypothesis 1. The increase in activation in the amygdala will modulate the hippocampus and increase the remembering of the emotional events preceding stimuli (13).

Hypothesis 2. More activation will occur in MTL and amygdala in the brain compared to neutral ones when functioning on emotional pictures (4).

Hypothesis 3. More activation will be observed in the frontal and medial lobes during the encoding of remembered stimuli compared to those forgotten (17).

This study is aimed at revealing the cause of the aforementioned effect with the cognitive paradigms using the fMRI technique. The fMRI technique has the potential to explain the sources of the impact of emotional events on remembering, as it allows us to examine the processes that take place in the brain while performing a task. The observed increase in memory performance may be due to emotional events affecting the consolidation processes. Emotional stimuli can affect how post-stimuli are processed.

Remembering the post-presented neutral stimuli may vary depending on participants' moods, their state of distraction source, or the clear strategies that can be applied. However, emotional events unlikely to increase the remembering of preceding stimuli, that is, not being displayed at that moment. Participants do not develop a specific strategy, because they do not know whether an emotional or neutral event will be presented following the neutral stimuli. The mood cannot affect the processing of neutral stimuli because emotional events are presented following the stimuli to be remembered. Presenting emotional events in post-neutral stimuli is expected to reduce memory performance, as demonstrated in various experiments (e.g., 25) in which emotional events are highly used for sources of distraction. To date, there has been no study testing such possibilities. In this context, the main purpose of our study is to reveal why emotional events increase the remembering of preceding stimuli.

Although behavioral experiments indicate that emotional events increase the remembering of preceding neutral events, no research has been conducted to show the reason for the observed increase in the memory performance. With behavioral experiments, the effect of independent variables on memory performance can be examined, but information about the processes taking place in the brain cannot be obtained. However, brain structures associated with cognitive processes can be revealed with the fMRI technique. The objectives of our study based on these needs are as follows:

1. Finding out why emotional events increase the remembering of preceding stimuli and the brain areas associated with this increase in performance,
2. To examine in which areas of the brain activation occur when studying emotional pictures compared to neutral ones,
3. To identify the brain areas associated with remembering and forgetting information by making a difference in how remembered and forgotten stimuli are processed during encoding.

METHOD

Sample

Sample size for planned repeated measures analysis of variance (ANOVA), was calculated using G * Power software based on one-way, 5% error, 80% power, and 0.35 effect size. The expected effect size is smaller than that obtained in the literature (0.51) (3). According to the power analysis results, it was determined that the sample size should be at least 15 people. 15 undergraduate students studying at Atilim University Faculty of Engineering, who took human-computer interaction course, had a right-hand preference, did not have any psychiatric disorders, were not using psychiatric or neurological medications, had normal or corrected normal acuity, and did not have any substance addiction, voluntarily participated into fMRI study. These students were given additional points for the course they took for their participation. Students who did not want to participate in the experiment were given assignments that they could complete in 2-3 hours in order to provide equal opportunities. The study was approved by the Atılım University Human Research Ethics Committee.

Experiment Design: 2-factor (the type of second stimuli; emotional, neutral) repeated measurement experiment design was used.

Validity Study: The second stimuli were chosen from Turkish culture instead of the International Affective Picture System (26) library, which reflects American culture. While the emotional pictures included scenes such as an earthquake, martyrs funeral, and terrorist incident; the neutral paintings included scenes such as a village coffee house, a school library, and road construction work. Stimuli were selected from the internet since no emotionally charged picture database reflects Turkish culture with norm data as far as we know in the literature. With the validity study, 248 pictures of the same size were presented to the participants in random order and in the middle of the screen without a time limit, and the intensity of excitement felt for each stimulus was asked to evaluate. While looking at the pictures, they were asked to press keys 1 to 9 on the keyboard, depending on how calm (1 key on the keyboard) or excited (9 key of the keyboard) was felt. As soon as the participant's assessment was received, the next stimulus was presented without a time interval. Different participants were recruited for validity and fMRI studies. A total of 48 pictures were used in the experiment, 24 negative with the highest arousal and 24 neutral with the least arousal.

Measures and Process

A signed consent form and MR information form were obtained from all participants before starting the experiment. Then Edinburg Handedness Inventory was applied. This experiment was designed according to the method of the study conducted by Anderson et al. (3). Accordingly, the first stimulus and then the second stimulus was presented in each trial. The first stimulus was selected from 48 neutral object pictures (such as plane picture, ant picture, apple picture, hand picture, table picture) obtained from the Snodgrass and Vanderwart database, which are frequently used in psychology experiments (27). These 48 black and white object pictures that individuals will work on were divided into two, resulting in two lists of 24 pictures each. The counterbalancing technique was used to assign these lists to experimental conditions. Thanks to this control method, each list was used equally in each experimental case. The presentation order of the pictures in each list was randomly determined for each participant.

According to the findings obtained from the validity study, 24 negative with the highest arousal and 24 neutral with the lowest arousal constituted the second stimuli of the study. Since variables such as human and animal presence are known to affect the remembering of pictures, the lists were created to be equal in terms of these two variables. Positive pictures were not used in this experiment to shorten the duration of the experiment, as Anderson et al. (3) showed that arousal, not the valence of the pictures, affects memory performance.

Stimuli were presented via a computer and projection device (NEC NP125) outside the MR room using the E-prime experimental package program (28). While on the MR device, participants saw the stimuli projected on the curtain with a mirror attached to the head coil. After the structural shooting, functional shots were carried out in 4 blocks of 12 trials each, only during the operation of stimuli. In each trial, participants were presented with a fixation mark (2 seconds) followed by the neutral-valued primary stimulus (4 seconds). Participants were asked to evaluate whether each object was living or non-living to process the stimuli in deep. In both lists created, half of the objects belonged to living beings and half to non-living beings. Volunteers were reminded of their duties by displaying the text "Live: Y N" right above the first stimuli (29). Participants were asked to respond to this task within 4 seconds. This text was displayed on the screen for 4 seconds, even if it was answered before this time. Two keys of the MR compatible response pad device (Current Designs, Philadelphia, United States) were used to collect the responses of individuals. The second stimulus, emotional or neutral, was then presented for 4 seconds. Participants were not assigned a task related to the second stimulus and were asked to only look at the stimuli. Following the object picture and emotional/neutral Turkish culture picture, mathematical operations (such as 5+6+7=18) were given to add 3 single-digit numbers for 15 seconds in each trial, and the accuracy of these operations was asked to evaluate. The purpose of this task was to prevent emotional stimuli from affecting other trials (3). Half of the operations shown on the screen were correct while the rest were incorrect. As soon as the volunteers' answers were received, a new mathematical operation was presented.

In studies examining the effect of emotion on memory through consolidation processes, one of the most common periods used between study and memory testing is 1 week (eg, 3,30,31). Therefore, memory performance in front of the computer was evaluated by the recognition test 1 week after all object pictures were studied. In this test, 48 studied object pictures and 48 unworked (new) object pictures taken from the same database were presented in random order. After each stimulus was shown on the screen for 2 seconds, the participants were asked whether they recognized the pictures and they were asked to press the relevant key. After pressing the key, the next stimulus was instantly presented. The remembering of the emotional and neutral pictures was also evaluated by the recognition test, and 48 old (24 emotional and 24 neutral pictures) and 48 new (24 emotional and 24 neutral) pictures were presented in a random order, similar to the object pictures.

MR Captures: MR images were taken with a 3-Tesla MR device (Magnetom, Trio TIM system, Siemens) at the National Magnetic Resonance Imaging Center. Anatomical images T1-weighted MP-RAGE (magnetization-prepared rapid gradient-echo) sequence [repetition time (TR): 2500 ms, echo time (TE): 3.03 ms, flip angle: 8°, acquisition matrix: 256×256, number of sections: 224, slice thickness: 1 mm, field of view (FOV): 25.6 cm×25.6 cm]. Functional shots T2* weighted EPI (echo planar imaging) sequence [repetition time (TR): 2000 ms, echo time (TE): 30 ms, rotation angle: 90°, acquisition matrix: 64×64, number of sections: 34, cross-section thickness: 4.8 mm, field of view (FOV): 19.2 cm×19.2 cm].

Behavioral Data Analysis: Statistical evaluations of behavioral data were made with SPSS 25 package program. The Kolmogorov-Smirnov Normality Test was used to test whether the data showed normal distribution. Since some variables did not display normal distribution ($p<0.05$), the Wilcoxon test was applied with paired samples that do not require normality assumption in the analyzes. The significance level was determined as ($p<0.05$) in statistical evaluations.

MR Data Analysis: Functional images were analyzed with AFNI 18.3.03 program (32). Individual analyzes were performed on each participant with afni_proc.py pyton script. 2 3D functional images captured at the beginning of each block were not included in the analysis to prevent the noise experienced during the stabilization stage of the MR signal. 3D functional images were pre-processed. In this context, despiking, slice timing correction, motion correction, coregistration of functional and structural images, spatial normalization, spatial smoothing, masking and scaling processes were performed, respectively. To eliminate the noise caused by possible discharges in functional data, the 3dDespike program, one of AFNI's recommended pre-processing steps, was used. Section timing correction was performed based on the first section captured. In the correction of head movements and the coregistration of functional and structural images, 3-D shooting with minimum outlier was taken as a basis. The spatial smoothing was performed with a Gauss-type kernel with a full width at half maximum (FWHM) of 4.5 mm. Anatomical and functional data were normalized in Talairach space according to Colin N27 template. With masking, automatic masks were created and non-brain areas were removed. In order to eliminate the signal difference between the participants and the shots, the data recorded as time series in each voxel was transformed into a percent signal change with respect to the mean by scaling.

A single gamma hemodynamic response function was used in modeling blood oxygen level-dependent (BOLD) responses. Beta coefficients of each predictor variable were found by general linear model (GLM) regression. In order to eliminate the effects caused by head movements, a total of 24 motion parameters, 6 in each block, were included in the regression analysis. In group analysis, beta weights obtained from GLM were examined by random effects variant analysis (ANOVA) in order to make generalizations in the universe. In order to avoid errors arising from multiple comparisons, cluster sizes with corrected significance threshold p <0.05 and uncorrected significance threshold p<0.005 in clusters determined by Monte Carlo simulations obtained through the 3dClustSim (with ACF option) program, and results exceeding these threshold values were reported.

RESULTS

Validity Findings

The arousal values of the selected negative images (Mean=7.14, SS=0.41) are higher than the arousal value of neutral images (Mean=2.16, SS=0.20) according to Mann-Whitney U test results (Z=-5.94, p<0.001). In order to examine the inter-rater reliability, the intra-class correlation coefficient was found to be at a good level (ICC=0.82, p<0.001) according to the criteria of Koo and Li (33). These results prove that the pictures selected from Turkish culture are valid and reliable.

Demographic and Neuropsychological Findings

Participants are between 21 and 29, with an average age of 23.07 and a standard deviation of 1.94. 8 of the volunteers were women whereas 7 of them were men. According to Edinburg Handedness Inventory, all participants preferred to use their right hand.

Behavioral Findings

The paired sampled Wilcoxon test was applied separately for each dependent variable (such as hit, false alarm, corrected recognition). In all these analyzes, the type of the stimulus (emotional, neutral) was used as an independent variable, and the false alarm rate was removed from the hit rate of each participant to eliminate the effect of predictions on memory performance (34). When analyzed with the corrected recognition values obtained, no significant difference between remembering the stimuli preceding emotional pictures (object pictures) and remembering the stimuli preceding neutral pictures (Z=-2.80, p=0.78). Similar statistically insignificant results were also found for hits (Z=-1.14, p=0.26) and false alarms (Z=-0.47, p=0.64) (Table 1).

As seen in Table 2, according to the corrected recognition results obtained from memory tests performed one week after the study to measure the remembering of secondary stimuli, it was observed that emotional pictures were remembered at a higher rate than neutral ones (Z=-2.53, p=0.01). The effect of the independent variable stimulus type (emotional, neutral) is also significant in hits (Z=-3.35, p=0.001) and false alarms (Z=-2.62, p=0.01).

During the study, no effect of the stimulus type (emotional, neutral) was observed in the accuracy of the mental processes presented in each trial following the primary and secondary stimuli (Z=-0.21, p=0.83) and reaction time (Z=-0.97, p=0.33). Similarly, the effect of stimulus type on other dependent variables such as the accuracy of the vitality assessment task (Z=-0.53, p=0.60) and reaction time (Z=-0.68, p=0.50) was not

Table 1: Hits, false alarms, and corrected recognition averages for pictures (primary stimuli) presented before emotional and neutral pictures

	Object pictures presented before the emotional pictures		Object pictures presented before the neutral pictures			
Variables	**Mean**	**SD**	**Mean**	**SD**	**z**	**p**
Hits	0.47	0.13	0.50	0.12	-1.14	0.26
False alarms	0.12	0.08	0.14	0.07	-0.47	0.64
Corrected recognition	0.35	0.08	0.36	0.11	-0.28	0.78

SD: Standard deviation

Table 2: Hits, false alarms, and corrected recognition averages for emotional and neutral pictures (secondary stimuli presented following the primary stimuli)

	Emotional pictures		Neutral pictures			
Variable	**Mean**	**SD**	**Mean**	**SD**	**z**	**p**
Hits	0.70	0.17	0.49	0.16	-3.35	0.001
False alarms	0.11	0.13	0.02	0.03	-2.62	0.01
Corrected recognition	0.59	0.19	0.47	0.16	-2.53	0.01

SD: Standard deviation

Table 3: Accuracy and reaction time averages in mental arithmetic and vitality assessment tasks

	Emotional pictures		Neutral pictures			
Variable	**Mean**	**SD**	**Mean**	**SD**	**z**	**p**
Mental Arithmetic Accuracy	0.91	0.05	0.92	0.02	-0.21	0.83
Mental Arithmetic Reaction Time	2307.30	728.54	2246.18	606.61	-0.97	0.33
Vitality Assessment Task Accuracy	0.92	0.06	0.93	0.04	-0.30	0.60
Vitality Assessment Task Reaction Time (ms)	1350.38	255.56	1385.04	342.28	-0.68	0.50

SD: Standard deviation

significant. The mean and standard deviation of these variables are given in Table 3.

fMRI Findings

As seen in Figure 1, it was found that the remembered stimuli caused more activation in the left inferior frontal gyrus (IFG) and left superior medial gyrus than the forgotten ones. Emotional pictures created more activation in the mid temporal gyrus and supramarginal gyrus compared to the neutral ones (Figure 2). The center of mass and voxel sizes of the activation areas in Talairach coordinates are given in Table 4.

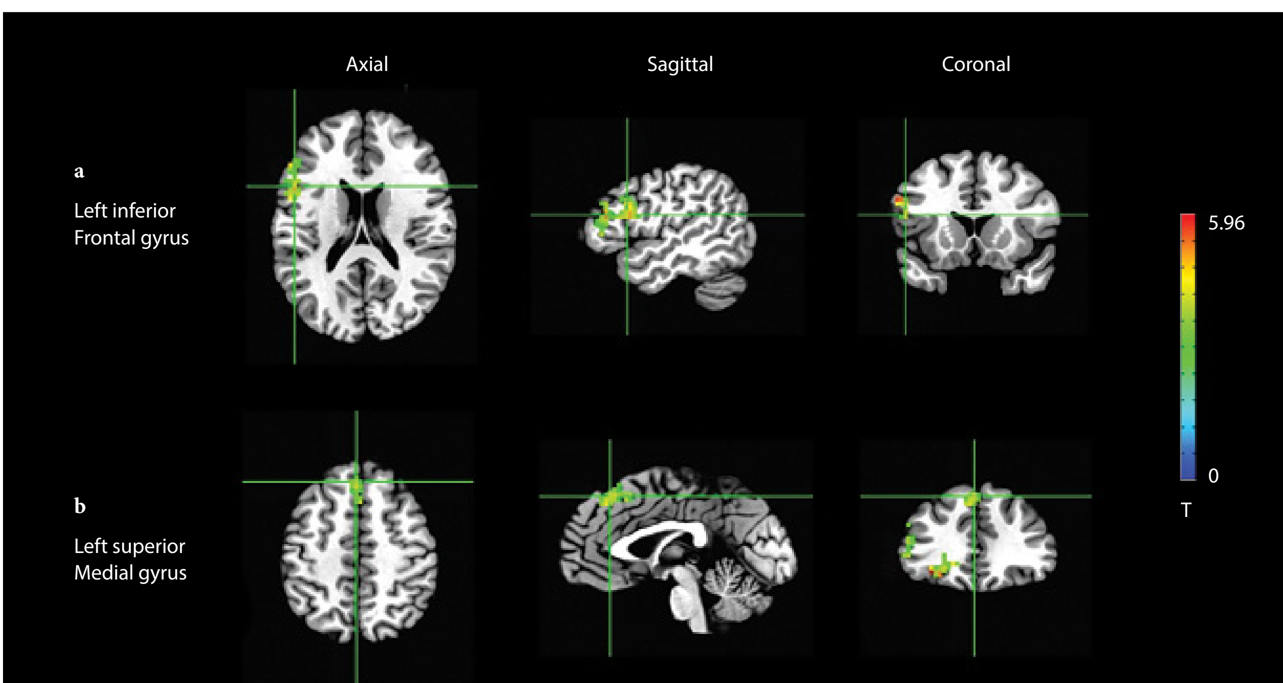

Figure 1. Activation areas associated with the Dm effect (Remembered>Forgotten) in the brain. (a) The activations observed in the left inferior frontal gyrus and (b) the left superior medial gyrus were imaged in the axial, sagittal, and coronal planes. Activation areas are shown in the anatomical image of Colin N27 based on T data. The left inferior frontal gyrus is a brain structure located in the lower parts of the frontal lobe as part of the prefrontal cortex. The left superior medial gyrus is located in the upper parts of the midline of the frontal lobe. These two brain structures are associated with the processes of semantic elaboration and the creation of associative memories.

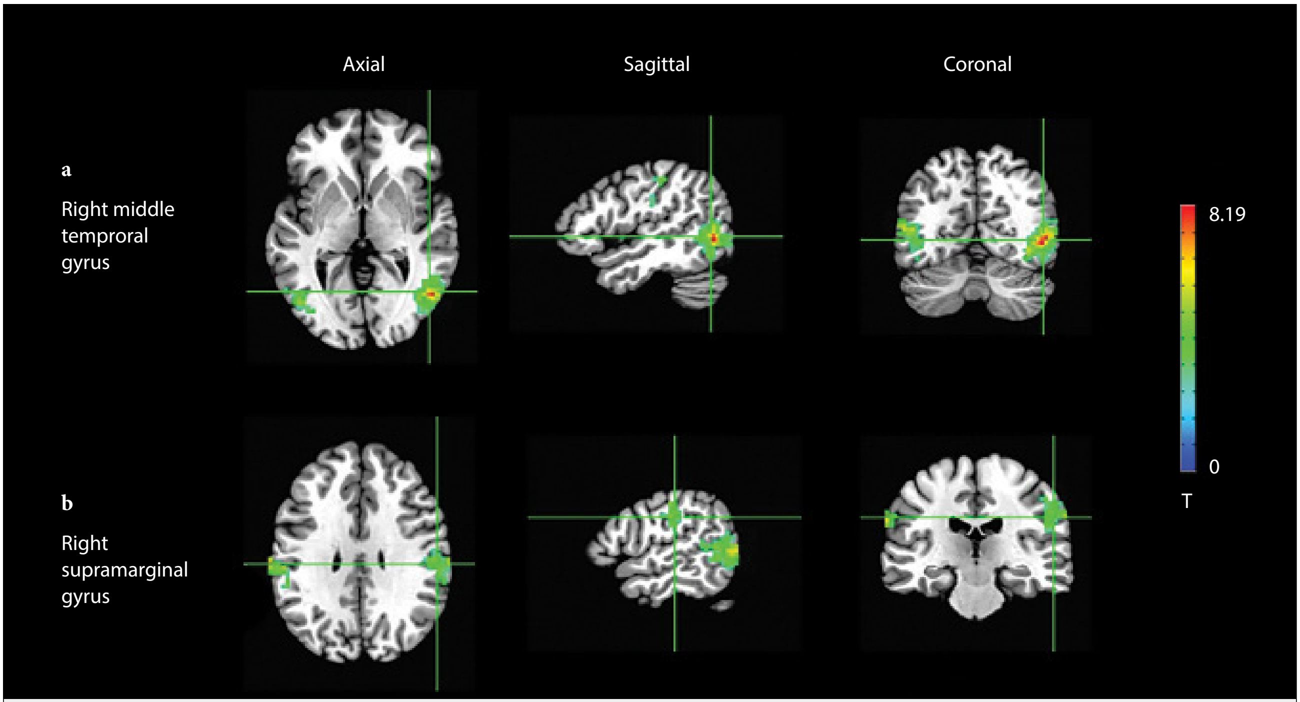

Figure 2. Activation areas associated with emotion (Emotional>Neutral) in the brain. The activations observed in (a) the right mid-temporal gyrus and (b) the right supramarginal gyrus were imaged in axial, sagittal, and coronal planes. Similar activations also exist on the left of the same structures. Activation areas are shown in the anatomical image of Colin N27 based on T data. The right mid-temporal gyrus is a brain structure located in the middle parts of the temporal lobe between the superior temporal sulcus and the inferior temporal sulcus and plays a role in the process of recognizing facial expressions that are a part of the ventral pathway. The Supramarginal gyrus is also known as Brodmann 40th area (BA 40). It is a part of the parietal lobe and the mirror neuron system and is a brain area involved in the processing of human gestures.

Table 4: Center of mass and voxel numbers of activation area associated with Dm and emotion effects

Comparison	Activation areas	Voxel number	Talairach coordinates (x)	(y)	(z)
Remembered>Forgotten	Left Inferior Frontal Gyrus	90	46.9	-16.9	21.3
	Left Inferior Frontal Gyrus	89	29.4	-26.7	-2.0
	Left Superior Medial Girus	47	2.3	-28.6	45.6
Emotional>Neutral	Right Middle Temporal Gyrus and Right Inferior Temporal Gyrus	235	-46.6	59.1	0.7
	Left Middle Temporal Gyrus and Left Fusiform Gyrus	174	42.6	57.5	0.1
	Right Supramarginal Girus	86	-54.0	23.2	30.9
	Left Supramarginal Girus	63	56.8	28.6	29.4

The center of mass of the activation clusters is given in RAI/DICOM coordinates. Negative values in the RAI (right, anterior, inferior) coordinate indicate the right direction. The size of each voxel is 3×3×3 mm^3, clusters with corrected significance threshold $p<0.05$ and uncorrected significance threshold $p<0.005$ on voxel basis are shown.

DISCUSSION

In this study, fMRI, one of the event-related neuroimaging techniques, which enables us to observe brain areas related to cognitive processes, which is widely used in the literature, was used. With this technique, it was aimed to show the brain areas associated with this effect in addition to the study of Anderson et al. (3) revealing that the preceding stimuli are better remembered. However, behavioral findings showed that neutral stimuli preceding emotional events did not provide better remembering. Hence, Hypothesis

1 did not support it. There are thought to be two reasons for this. First, the study was carried out on an fMRI device in a laboratory environment, which is the opposite of the participants' daily lives. Second, although it will be explained in detail above, the emotional (negative) pictures used in the study did not sufficiently affect the participants.

Thereupon, the activation differences during the processing of emotional and neutral stimuli in fMRI findings were examined, and it was found that emotional stimuli caused activation in four different areas, unlike the neutral ones: the mid-temporal gyrus (MTG), inferior temporal gyrus, fusiform gyrus and supramarginal gyrus. However, since no activation was found in the main areas of the brain (amygdala and MTL regions) where the emotional stimuli stated in Hypothesis 2 were expected to be activated, the Dm effect was examined and it was observed that the stimuli remembered on the left IFG and left superior medial gyrus caused more activation.

Comparing the remembering of the emotional pictures with that of the neutral pictures, it was found that the participants recognized the emotional pictures at a higher rate than the neutral pictures, in accordance with the literature (eg, 6). When looking at the fMRI findings, emotional pictures cause activation in four areas in the brain compared to neutral ones: MTG, inferior temporal gyrus, fusiform gyrus and supramarginal gyrus. Although MTG is a part of the visual ventral pathway, there is not enough information about its function (35). In the literature, there are studies showing that MTG is activated in the processing of negative facial expressions (such as angry, sad) (36), negative pictures (37), and involves in the object recognition process (38). Considering the use of negative and neutral images in this study, object recognition is expected to occur for both emotional and neutral pictures. The reason why MTG activation is more for negative pictures at this point, may be due to the processing of negative pictures rather than the object recognition process. This interpretation is also supported by the activations in the inferior temporal gyrus, fusiform gyrus, and supramarginal gyrus during processing of negative stimuli (39,40). Although the inferior temporal gyrus is a part of the ventral pathway with MTG, it plays a role especially in the object recognition and facial expression process (41). Fusiform gyrus is known for being involved in color recognition and facial expression processing (40). Finally, the supramarginal gyrus is a part of the mirror neuron system and is an area of brain involved in the processing of human gestures (42). Looking at their common points, we can conclude that negative facial expressions of all areas are involved in the encoding process. The emphasis on emotion in the pictures used in the study is usually human facial expressions (such as people crying or expressing desperation). Considering all these, we can conclude that MTG, inferior temporal gyrus, fusiform gyrus and supramarginal gyrus are activated during the recognition process of the negative facial expressions in accordance with the literature. When evaluating this result, it is likely that the participants paid attention to the facial expressions in the pictures, as most of the secondary stimuli used in the experiment contained human faces. In summary, emotional pictures were found to generate more activation in the MTG and supramarginal gyrus than neutral ones, and as these brain structures were responsible for the processing facial expressions, the participants were thought to pay attention to how people felt in the emotional pictures with predominantly human face. For example, it should be looked at the people's facial expressions to see if they're suffering or sad. In this case, the association of the activated brain areas with the processing both the negative pictures and facial expressions can be explained by considering the emotional emphasis of the pictures used.

Although our study found activation in brain areas associated with emotional facial expressions, no activation was observed in the expected amygdala and MTL associated with emotional stimuli. Therefore, the findings do not support Hypothesis 2. Among the reasons why the expected results were not achieved may be that the pictures presented in the study did not affect the participants sufficiently. Considering Turkey's agenda, a new one is added frequently to the events such as terrorism, natural disasters, crime, violence against women and children and even in many television series and Turkish film such events are conveyed as if they were part of daily life (eg., 43-46). For example, one third of the total time contain violence in television broadcasting five channels in 80 films shown in Turkey (46). It is possible that these facts exist for the Turkish people, who may be exposed to news and images such as death and violence, whose emotional intensity is probably more than the pictures used in the media for information and entertainment purposes every day in our study, became commonplace over time, and therefore the pictures presented in our study did not affect the participants as expected (47). As a result, the amygdala and MTL regions may not have been activated, because the pictures presented in the experiment did not cause sufficient emotional arousal in the participants. Accordingly, it is a normal result that the object pictures presented preceding emotional stimuli are not remembered better.

Another reason why emotional stimuli may not increase the remembering of preceding object pictures may be that the participants did not pay enough attention to these emotional pictures (25). When the behavioral data are examined, it can be seen that the accuracy of emotional stimuli is 0.70 (Table 2). This memory performance obtained in the recognition test one week later supports that the participants paid attention to emotional pictures. Another reason for not achieving the expected results may be that the arithmetic process given after emotional stimuli consumes limited mental resources. According to the model of Mather et al. (22), stimuli compete for limited mental resources, emotional events in such a competition take precedence and enable better remembering of information around them. Participants who want to perform the arithmetic process correctly and quickly after emotional stimuli may have given their limited mental resources to this task, and therefore, there may not be enough mental resources left for emotional stimuli to increase memory.

When the activation differences between the encoding of the remembered and forgotten object images were examined, more activation was found in the left IFG and left superior medial gyrus in remembered stimuli compared to those forgotten. These results support Hypothesis 3. At this point, there are studies in the literature showing that the activations in the frontal and medial lobes can predict the Dm effect (48). The IFG, which is a part of the prefrontal cortex whose activation is expected especially for the Dm effect, is involved in semantic elaboration and associative memory formation processes that support the formation of memories (4,49,50). Considering the relationship between processes such as forming elaboration and associative memories with deep processing, it can be concluded that remembering stems from deep processing (29). Given the studies showing that emotional stimuli are involved in deeper encoding processes than the neutral ones (51), semantic encoding of emotional stimuli may provide better remembering of these information compared to neutral ones. To support this possibility, in a study (52) that took the semantic elaboration level as a variable found that the semantic-based encoded stimuli were better remembered than perception-based stimuli.

In addition, the pictures presented to the participants are also an important factor that evokes them. IFG is also involved in the formation of associative memories. In this study, the stimuli presented were selected from the Turkish culture pictures. Therefore, participants may find pictures that can easily be related to their past experiences and daily lives in the pictures and thus they can better remember some pictures. However, the superior medial gyrus activation supports the IFG's semantic elaboration activation. It is known that the superior medial gyrus located in Brodmann 8th area (BA 8) plays a role in attention and semantic elaboration processes (53). Studies on the Dm effect have also shown the activation of BA 8 in remembered stimuli (54). The observation of BA 8 activation in remembered stimuli is consistent with the finding in the literature that remembered stimuli are better remembered by their involvement in the semantic elaboration process. In summary, more activation occurred in the left IFG and left superior medial gyrus areas of the brain than those forgotten during the processing of remembered stimuli. Since the relationships of these brain structures with the processes of semantic elaboration and associative memory formation are known, the more semantic elaboration and personal memories that participants create when encoding stimuli, the better they will remember the information.

Looking to the factors limiting the study, the fact that the pictures used belonging to Turkish culture may lead to associative learning, since it is more likely to coincide with the lives of the participants. The selected pictures can create different emotions among the participants. Therefore, emotional picture libraries adapted to Turkish culture can be developed in future studies and these stimulus sets can be used in memory experiments. In addition, only negative pictures were used in the study, based on studies showing that the participants were affected by the arousal of emotional stimuli, not the value (positive or negative). However, some studies in the literature have found that there are different areas of activation for positive stimuli. Subsequent studies may examine the differences that can be observed in presenting positive pictures. In addition, the emotional emphasis in the stimuli used in this study was on facial expressions. Future studies may investigate the change in activation areas by keeping other variables in the pictures (valence, arousal and the number of pictures with a human face) constant and displacing the emotional emphasis. In this way, it can be seen whether the participants were affected by facial expressions in the pictures or the emotional arousal of the pictures.

In summary, our research has not shown that emotional stimuli increase remembering of preceding neutral stimuli. However, activations in the MTG, inferior temporal gyrus, fusiform gyrus and supramarginal gyrus were found in the processing of negative pictures compared to neutral stimuli in the brain. These areas are related to the processing of emotional facial expressions. These activations can be explained by the fact that in the pictures used the emotional emphasis was on the facial expressions. In addition, when looking at the Dm effect, activation was detected in the left IFG and the left superior medial gyrus. These activations are associated with semantic elaboration processes. These findings can be explained by the result that the object pictures are remembered for their deeper processing. Although there are many studies on emotion and memory in our country, studies investigating how cultural variables affect emotion and memory can provide significant contributions to the literature.

Contribution Categories		**Author Initials**
Category 1	Concept/Design	E.O.
	Data acquisition	E.O.
	Data analysis/Interpretation	E.O., B.K.
Category 2	Drafting manuscript	E.O., B.K.
	Critical revision of manuscript	E.O., B.K.
Category 3	Final approval and accountability	E.O., B.K.
Other	Technical or material support	E.O.
	Supervision	E.O.

Ethics Committee Approval: The study was approved by the Atilim University Human Research Ethics Committee (Number: B.30.2.ATL00.02.03/09-2183, Date: 04.08.2009).

Informed Consent: Written consent has been obtained from the participants.

Peer-review: Externally peer-reviewed.

Conflict of Interest: The authors declared no conflict of interest.

Financial Disclosure: This study was supported by the Scientific and Technological Research Institution of Turkey.

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