The Science Journal of the Lander College of Arts and Sciences

Volume 7
Number 1 *Fall 2013*

Article 11

1-1-2013

The Effects of Emotional Experiences on Memory Processing

Naomi Berkowitz
Touro College

The Effects of Emotional Experiences on Memory Processing

Naomi Berkowitz

Abstract

Neural regions, specifically the amygdala, hippocampus, and prefrontal cortex overlap in functions of emotion and memory, indicating a degree of interrelatedness between the two functions. Lesions in medial temporal lobe regions result in an impairment of memory processes specific to emotional stimuli. Additionally, amygdala activity is increased for all valence memory as opposed to neutral. Arousal levels of high and low valence memories affect the pathway for encoding in the brain, and determine the vividness and episodic detail with which a memory will be recorded. The amygdala-hippocampal network is involved in high arousal memory, while a prefrontal cortex-hippocampal network is involved in low arousal. Because of the different neural pathways, negative memory is better remembered, while positive memory is better known. Males and females display the same abilities in working memory, yet have differing neural pathways. Because males' memory networks are more associated with the prefrontal cortex, they have better cognitive control than females for emotional events. Some suggest that because of the implications of a prefrontal vs. amygdala memory encoding, emotional regulation at the onset may be key to preventing traumatic memories from ever developing. Further research should be done in defining the link between emotional and memory processing, to better understand and provide therapy for various neurological disorders.

Introduction

The field of affective neuroscience addresses the biological basis of emotions. Affective neuroscientists attempt to explain what an emotion is, and how emotional processes interact with other areas and functions of the brain. Neuroscientists over the years have associated emotions with a network of structures in the brain, specifically the limbic system. The limbic system includes parts of the orbital and medial prefrontal cortices, part of the thalamus, the amygdala, the hippocampus, and the cingulate cortex (Figure 1). Many of these same structures, aside from control of emotions, are responsible for various functions of memory. Specifically, the prefrontal cortex, hippocampus, and amygdala are known to play significant roles in memory processing, encoding, and storage. Because of the overlap of brain structures for these two different functions, there is strong evidence of a connection between emotion and memory. Many neuroscientists have asked and will continue to ask what the exact interrelatedness of these functions is.

Aside from understanding the relationship between various memory processes and different types of emotional experiences, many new questions emerge because of it. Are there differences in male and female memory processing because of the way emotions affect each of them? How does a disturbance in this relationship affect people? Does it explain any mental abnormalities? Furthermore, this connection, should it be biologically proven, leads the way to areas of human manipulation in encoding memory, based on their emotional experiences. Questions of memory repression and other similar issues can also be biologically tested.

Emotion

The Limbic System is specifically associated with emotion, yet a conclusive localization of specificity of brain structures for each emotion has not been clarified. Neuroscientists have discovered different activity for positive versus negative emotion, but not complete specificity for a particular positive or negative emotion. The most consistent research regarding specificity of emotional function is in regard to a lateralization of function. Increased activity in the left frontal and temporal lobes is associated with the Behavioral Activation System, emotions which cause a person to outwardly react, such as happiness or anger. Emotions such as fear and disgust, which inhibit a person's behaviors, are associated with increased activity in the right frontal and temporal lobes (Kalat 2013).

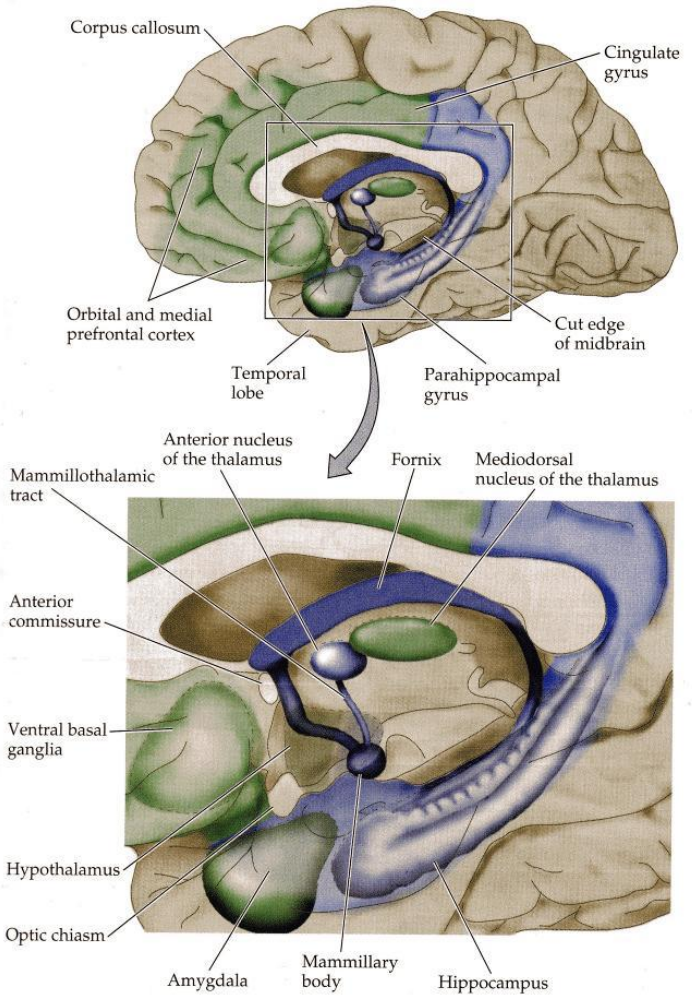

Figure 1: The Limbic System. Source: Purves et al, 2001.

Naomi graduated in 2013 with a B.S. degree in biology.

The major neural structures for emotional processing discussed in this paper include the amygdala, hippocampus, and prefrontal cortex (PFC). Most research has been conducted regarding the amygdala, because of its primary role in emotional functions.

When classifying an emotion, the experience is rated based on its valence and arousal. The valence of an emotion refers to how positive or negative an experience is. High valence is a pleasant feeling, and low valence is an unpleasant one. Arousal is the degree of intensity of emotion that an experience causes. High arousal results in feeling excited or anxious, while low arousal in feeling calm or subdued. An experience can be high valence, high arousal (winning the lottery), high valence, low arousal (getting a massage), low valence, high arousal (a screaming match), or low valence, low arousal (mourning). These factors are key in regard to measuring specific brain activity.

Memory

The two basic divisions for memory are short term memory and long term memory. Short term memory, now known as working memory, is a piece of information that our brain holds onto temporarily, as long as it's being rehearsed and focused on. There are two parts to processing long term memory. First, there is the original formation and encoding an image or event. Later there is the recall or retrieval of the memory, which is referred to as the subsequent memory.

Long term memory is memory that is stored by the brain, and can be subdivided into two major categories: explicit and implicit memory. Explicit, or declarative, memory refers to things that the brain consciously committed to memory. Things unconsciously absorbed by the brain are considered implicit memory. Implicit memory is known as procedural memory; it does not just include events or images, but refers to skills or procedures that are learned. Explicit memory can further be subdivided into episodic and semantic memory. Episodic memory is also known as autobiographical memory, because it refers to memories related to a specific occasion in a person's lifetime. Other pieces of known information, which are basically general knowledge that a person acquired, are semantic memories.

The major brain areas involved in memory functions include regions in the prefrontal cortex, hippocampus, amygdala, cerebellum and basal ganglia. Each structure plays a part in the overall processing of memory. Two major functions of the PFC are in working memory and autobiographical memory. The hippocampus is necessary for explicit memory, spatial memory, and episodic memory. The amygdala's function is in encoding and enhancing emotional memory. The cerebellum and basal ganglia play a major role in implicit memory. The processes of the PFC, hippocampus, and amygdala will all be discussed because of the emotional function of these structures as well.

Measuring Brain Activity

Studies conducted by affective neuroscientists generally have a behavioral phase and a neurological phase. Most experiments involve presenting various standard neutral or emotionally stimulating images or verbal cues. The cues can be classified based on valence and arousal for a more specific study. These images or words are then evaluated emotionally by the subjects, both by recording their behavioral responses and by viewing their brain function under an EEG, fMRI, or PET scan. Later on, these images are displayed again, and the subjects recall is evaluated, both by their behavioral responses and by neuroimaging.

An EEG, or electroencephalogram, measures brain activity via electrodes by the electrical current being produced. The electrical activity of brain regions is measured as the subject is responding to a behavioral cue. For 3D imaging, PET scans and fMRI scans are conducted. PET scans involve the injection of a radioactive tracer, which can highlight brain regions based on the oxygen or glucose levels in those regions. An fMRI scan measures localized brain activity by measuring the levels of cerebral blood flow based on the oxygen levels of neural regions. Because of the advantages of projecting a 3D image and a lack of radioactive injections, fMRI scans are the most commonly used to determine brain function.

Aside from neuroimaging, researchers study brain activity in patients with lesions to various brain structures in comparison to the average human brain. For these studies, comparing behavioral results explains the effects of a removal of certain neural regions.

Methods

The research for this paper was collected via searches on the Touro College library database. Databases where articles were found include PubMed, ScienceDirect,, MD Consult, ProQuest, and EBSCO. The above listed databases include a vast library of journal articles related to medicine and the health sciences. The studies were collectively analyzed to draw consistent conclusions, regarding research in the area of emotion and memory.

Discussion

Neutral VS. Valence Memory

To establish a direct link between emotional arousal and memory processing, researchers studied patients with lesions in their medial temporal lobes (Ahs et al, 2010). The medial temporal lobe (MTL) contains the anterior part of the hippocampus and the amygdala. The hippocampus is involved in retrieval of all memory, and the amygdala is involved in the encoding of emotional memory, which enhances the memory performance for high arousal stimuli. The amygdala is also involved in enhancing emotional declarative memory. A study was conducted with control subjects and patients who had medial temporal lobe lobotomies, in either their left or right hemispheres. Various emotional images were displayed to the

subjects, and the recognition of these images was tested immediately afterward. The results revealed no difference between the controls and patients for neutral items, yet there was a significantly higher percentage of recall for all emotional items in the control subjects. This held true for all valence items, regardless of their arousal. Within the control group, there was a slight incremental increase in recall for valence items of higher arousal. There was no observed difference for arousal memories among patients with a lesion to the medial temporal lobe in one hemisphere or the other. The study did not reveal significant difference in recall for patients with right versus left MTL lobotomies. Other studies, however, do reveal poorer recall for those with left versus right MTL lesions (Buchanan et al, 2001). They studied how neutral versus emotional verbal cues affect memory processing. There is left lateralization for verbal processing of emotional information, which explains why those with a left MTL lobotomy have worse retention for emotional, verbal stimuli.(Buchanan et al. 2001)

In investigations of people with MTL lobotomies, the focus of the experiments was the amygdala. However, these studies were not conducted with patients who exclusively had lesions in the amygdala. Therefore, a more selective study was done, using subjects with damage to their amygdalae specifically (Adolphs et al, 2005). This study more accurately concluded revealed similar results as the above mentioned studies; enhanced processing for emotional memory occurs when the amygdala is involved in encoding. However, this study made a further, more specific observation, in terms of the amygdala's role in memory consolidation and retrieval. After studying patients with amygdala damage, these researchers compared the MRI scans of subjects with MTL damage. The volume of amygdala damage in the MRI directly correlated with the impairment of the general gist of emotional memories, while the volume of hippocampal damage directly correlated with the impairment of the contextual details of those memories.

Emotional Enhancement of Memory: Which Functions?

Neuroimaging allows for localization of brain activity under various environmental stimuli. It is known that increased amygdala activity leads to a better encoding of emotional memory. However, it is unclear whether this refers to the vividness of the memory or its episodic details. , Researchers used an fMRI study to determine what sort of emotional memory is better encoded by presenting subjects with images of various arousal and valence levels (Kensinger et al, 2011). They stated that there are different processes which reflect the vividness of a memory versus its episodic details. The fMRI scan revealed increased amygdala activity for memories with increased vividness, but not episodic detail. This held true for all types of emotional memory, regardless of the memory's valence or arousal level. However, higher activity in many regions of the prefrontal cortex was associated with an increase in vividness for high arousal memories. In contrast, increased activity in the occipital and inferior temporal lobes was related to increased vividness for low arousal memories. These different memory paths have significance in explaining behavioral tests of memory. High arousal memories are often reported to be more vividly recalled than low arousal memories. Because of the involvement of the prefrontal cortex, this greater vividness is due to other types of memory functions of the PFC, such as autobiographical memory.

Another study, specific to the role of the PFC in emotional processing, revealed increased activity in an fMRI scan in various PFC regions, depending on the sort of emotional experience (Dolcos et al, 2004). There was overall greater activity in the left ventrolateral and dorsolateral PFC for emotional versus neutral stimuli. The left dorsolateral PFC revealed greater activation for positive images, while the right ventrolateral region revealed greater activation for negative. This is consistent with the lateralization effect for emotional experiences.

When an emotional memory is being encoded, a high arousal memory is often more confidently vividly recalled, but there is actually no increase in encoding of details of the memory. Low arousal memories are just the opposite. They are not reported to be as vivid, but are more accurately recalled and contain contextual details, because of the sensory pathway involved in forming low arousal memory. In terms of increased episodic detail, the fMRI scan revealed no increased activity in the amygdala for better encoding of details (Kensinger et al, 2011). There was activity in the lateral prefrontal cortex, hippocampus, and anterior cingulate gyrus; these areas are all associated with binding contextual details, and are involved in neutral and emotional memory. There was increase in activity in the occipital and inferior temporal lobes for better recall of episodic detail in negative valence memory (more so than positive). This is why negative memory is encoded with more sensory detail than positive memory. The fMRI also revealed greater activity in the frontal and temporo-parietal regions for greater episodic recall of low arousal memory. This is consistent with the knowledge that those regions are associated with elaborative and semantic memory processing.

Another study was conducted to test a "trade off" effect for emotional enhancement of a memory versus the background details (Waring & Kensinger, 2011). Based on the valence and arousal of the stimuli, a memory is encoded via different pathways in the brain, which result in this trade off. Specifically, high arousal valence experiences are processed via an amygdala-hippocampal pathway, while low arousal valence experiences are processed via a PFC-hippocampal network (Kensinger & Corkin, 2003). Though studies proved a greater recall rate for valence, low arousal over neutral memory, the encoding pathway is quite similar. Subjects of an experiment were observed under an fMRI, while being presented with words that were either neutral, negative high arousal, or negative low arousal. After a short delay, these subjects were again observed under fMRI for their ability to recall these words. The scan for initial formation revealed increased activity in the left hippocampus, amygdala, and inferior parietal lobule for all the negative words versus the neutral words. (The inferior parietal lobule is believed to be involved in processing

verbal information that is related to the self, attention, and emotional content.) The left inferior and dorsolateral prefrontal cortices showed greatest activation for negative low-arousal words than for any other words, because of the left PFCs function in semantic memory. When the subjects were evaluated for subsequent memory, the fMRI scan showed increased activity in the left amygdala and hippocampus for the high-arousal words (Kensinger & Corkin, 2003). The recalled negative non-arousing and neutral words revealed increased activity in the left inferior PFC and left hippocampus.

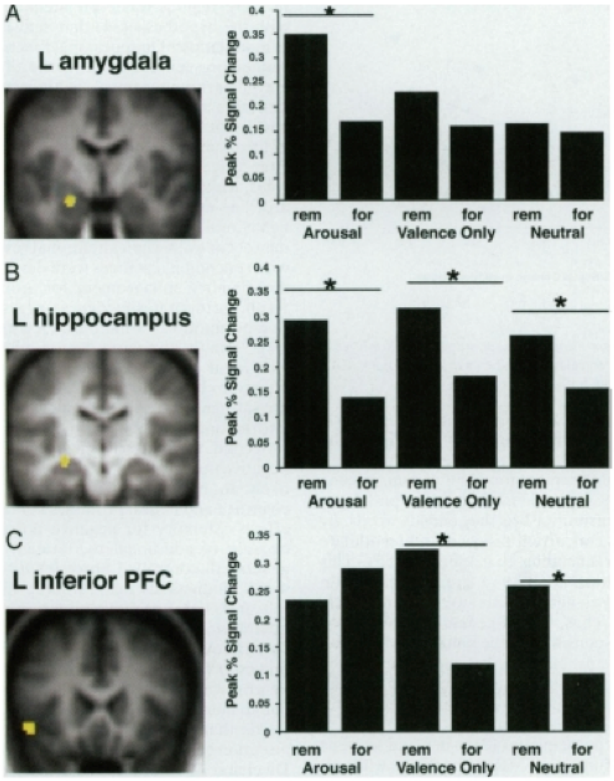

Figure 2: Graphs with their corresponding imaging scans, comparing activation in the amygdala, hippocampus, and prefrontal cortex for remembered (rem) and forgotten (for) neutral, valence, and arousal memories. Source: Kensinger & Corkin, 2003.

The results of many studies (Kensinger & Corkin, 2003, Kensinger et al, 2011, Dolcos et al, 2004) conclude that the amygdala is involved in an increase of the vividness of the memory because of encoding a particular set of the details. Contextual and episodic details, overall, are not better recalled because of the amygdala. These results are consistent with the above mentioned studies of amygdala and MTL lobotomies, which conclude that the amygdala is involved in emotional enhancement of memories, processing of the gist of the memory, but not encoding details (Adolphs et al, 2005). This memory recorded via the amygdala is often very subjective, as the person very vividly remembers only certain details of the experience.

An advantage of the amygdala-hippocampus pathway for high arousal items is that it occurs almost always and automatically (Kensinger & Corkin, 2003). In contrast, the PFC-hippocampus pathway for low arousal items requires attention and control. A small behavioral study to the same subjects of the fMRI scan was conducted, during which retrieval for neutral, low arousal, and high arousal was measured while the subjects were multitasking. The results revealed only a significantly greater recall percentage for the high arousal words over the neutral words while the subjects had to focus on other things.

High and Low Valence

The above studies show that arousal levels affect memory processing, but do not differentiate between positive and negative experiences. To gain this understanding, a study was conducted to examine the effects of valence on memory (Mickley & Kensinger, 2008). The study established two distinctions. First, that all emotional stimuli are remembered via the orbitofrontal cortex. However, after a longer delay of re-displaying the stimuli, negative information was "remembered" more than positive memory was. Positive information was remembered less, but had a higher rate of being "known". Under fMRI imaging, areas of the temporo-occipital lobe displayed high levels of activity for low valence emotional experiences. This is because negative memory is associated with higher sensory encoding, and is therefore more likely to be remembered. In contrast, positive memory shows high activity in the cingulate gyrus and parietal lobe. These areas are associated with both semantic and episodic memory retrieval and with poor encoding of specific details. This explains why positive memory is known rather than remembered after a long time delay. When a positive image is displayed, often a person gets distracted by personal positive memories that are triggered, because of association with that image. Therefore, the small details of the specific positive image are lost, because more memory is involved with a positive memory. Both emotionally positive and negative stimuli have pathways in the brain for better memory encoding, more so than neutral memory. Each category of emotional memory, however, has its own specific pathway related to the emotional experience.

Gender Differences

Because of the relationship between emotion and memory, researchers asked if there are any gender-related differences in these processes. Women are generally more emotional than men; biologically this means that women's orbitofrontal cortices are more activated than men when processing emotions induced by olfactory stimuli. Statistically, prevalence rates for emotional disorders are higher in women than men. Additionally, women are more prone to display physiological signs of emotion than men are. Men, however, display greater cognitive control over their negative emotions. In a controlled experiment, male and female subjects were presented with a behavioral test for working memory (Koch et al, 2007). The subjects were prompted to focus on one letter being displayed, and also verbally recall a letter that they had just seen. While they were involved in this task, a negative odor was periodically being sprayed into the room. Both males and females were observed to have impaired working memory while the negative

odor was presented. However, the females did not perform any worse on the tasks than the males. An fMRI scan was taken of the subjects while they were conducting this task with a neutral odor, and with a negative one. Males and females revealed activation in different brain areas for working memory, regardless of the odor. Males revealed greater activity than females in the lingual gyrus, while women displayed greater activity than men in a complex neural network, including areas of the prefrontal cortex, temporal lobe, and cingulate gyrus.

When the negative odor was presented, women revealed greater activation in the left superior temporal gyrus, right inferior frontal gyrus, and left insula. In comparison of the interaction between working memory and the negative olfaction, males displayed higher activity in the left inferior parietal lobe, right middle temporal gyrus, and left superior occipital lobe than females. Females displayed greater activation in the left amygdala and right orbitofrontal cortex (OFC).

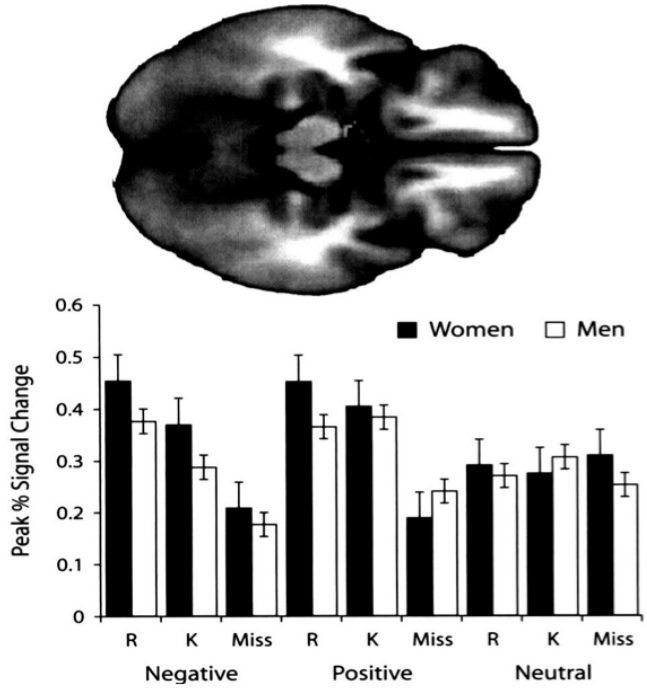

Figure 3: Graph comparing increased amygdala activation in males and females, for subsequent memories of varying valence experiences, that were remembered (R), known (K), or missed (Miss). Source: Koch et al, 2007.

The neural regions where females displayed greater activity when the negative olfaction was introduced are associated with processing negative emotions. In females, emotion and cognition are two parallel networks; the network for working memory in females was not affected when an emotional stimulus was introduced. However, in males, there was increased activity in areas which overlap with cognitive function. The cognitive and emotional processes in males are activated via the same brain pathway, as was observed in comparison of the fMRI results for an interaction between the memory task and the odor. Because of this shared pathway, men are better able to cognitively control their emotions.

Emotional Regulation: Affects on Memory Encoding and Retrieval

Research has shown that when the amygdala is activated because of an emotional experience, long term memory is better encoded (Dolcos et al, 2004). A study was conducted to test whether this applies when people regulate their emotions, as opposed to emotions that are experienced naturally (Erk et al, 2010). Subjects viewed neutral and negative images, and were asked for some of these images to allow themselves to naturally feel, and for some to regulate their emotions. One year later, some of the same images as well as new images where were displayed to the participants, and they were prompted to respond if they recalled the images. An fMRI scan of the subjects revealed that for all the negative images, there was brain activity in the amygdala, prefrontal cortex, occipito-temporal cortex, and brainstem. When an image was correctly recalled, there was brain activity in regions of the left prefrontal cortex, midbrain, parietal lobe, hippocampus, and amygdala. Regarding the question of emotions regulated or naturally experienced, the fMRI showed activity in the right amygdala when the naturally experienced emotional images were recalled. The behavioral results exhibited a similar percentage of correctly recalled memories for all negative images. However, for those that were regulated, there was no increased activity in the right amygdala. The regulated memory

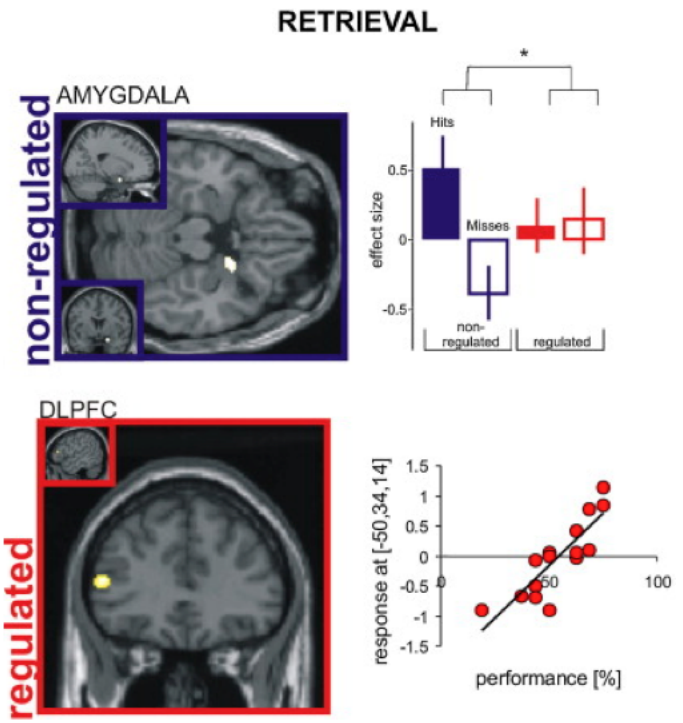

Figure 4: Scans comparing amygdala activity for non-regulated emotional stimuli and activity in the dorsolateral PFC for regulated emotional stimuli. Source: Erk et al, 2010.

showed increased activity in the right dorsolateral prefrontal cortex. This explains that all negative memory has a greater recall accuracy than neutral memory, but that the encoding pathways of the brain differ. The neural route of a memory is dependent whether or not it was experienced emotionally (Ochsner et al, 2002). When negative information is encoded as the emotion is processed, then the amygdala will be active when the memory is recalled (Erk et al, 2010). This resurfacing memory does not only bring forth the image, but also the emotions associated with it. If the negative information is originally encoded by emotional regulation, then when the memory is recalled via the prefrontal cortex, it will only be a cognitive experience (Ochsner et al, 2002). These results suggest that if the brain can regulate its recording of negative events, then these events will not, in the future, cause emotional stress or trauma.

Conclusion

This review concludes that emotional stimuli affect the pathways of memory encoding. Specifically, when the amygdala is activated at encoding, the memory that is stored will be vivid and may arouse emotion when retrieved. Many factors may contribute to a neural network with less amygdala involvement, and instead cause the prefrontal cortex to be more active in memory formation. There is greater cognitive control, in terms of episodic detail and emotional regulation, when memory is processed via the PFC. More research in this area should be conducted, because of the potential benefits that a clearer understand of encoding of emotional memories may have on patients with depression, post-traumatic stress disorder, and other mood and anxiety disorders.

References

Adolphs R, Tranel D, Buchanan T. 2005. Amygdala Damage Impairs Emotional Memory for Gist but not Details of Complex Stimuli. Nature Neuroscience 8(4): 512-518.

Ahs F, Kumlien E, Fredrikson M. 2010. Arousal Enhanced Memory Retention is Eliminated Following Temporal Lobe Resection. Brain and Cognition 73(3): 176-179.

Buchanan TW, Denburg NL, Tranel D, Adolphs R. 2001. Verbal and Nonverbal Emotional Memory Following Unilateral Amygdala Damage. Learning and Memory 8(6): 326-335.

Dolcos F, LaBar KS, Cabeza R. 2004. Dissociable Effects of Arousal and Valence on Prefrontal Activity Indexing Emotional Evaluation and Subsequent Memory: An Event related fMRI Study. NeuroImage 23(1): 64-74.

Erk S, von Kalckreuth A, Walter H. 2010. Neural Long Term Effects of E. motion Regulation on Episodic Processes. Neuropsychologia 48(4): 989-996.

Kalat, JW. 2013, 2009. Biological Psychology. 11th Edition, Wadsworth, Cengage Learning.

Kensinger EA, Corkin S. 2003. Two Routes to Emotional Memory: Distinct Neural Processes for Valence and Arousal. Proceedings of the National Academy of Sciences of the United States of America 101(9): 3310-3315.

Kensinger EA, Addis DR, Atapattu RK. 2011. Amygdala Activity at Encoding Corresponds with Memory Vividness and with Memory for Select Episodic Details. Neuropsychologia 49(4): 663-673.

Koch K, Pauly K, Kellermann T, Seiferth NY, Reske M, Backes V, Stocker T, Shah NJ, Amunts K, Kircher T, Schneider F, Habel U. 2007. Gender Differences in the Cognitive Control of Emotion: An fMRI Study. Neuropsychologia 45(12): 2744-2754.

Mickley KR, Kensinger EA. 2008. Emotional Valence Influences the Neural Correlates Associated with Remembering and Knowing. Cognitive, Affective, and Behavioral Neuroscience 8(2): 143-152.

Ochsner KN, Bunge SA, Gross JJ, Gabrieli JD (2002): Rethinking Feelings: An FMRI Study of the Cognitive Regulation of Emotion. Journal of Cognitive Neuroscience 14:1215–1229.

Purves D, Augustine GJ, Fitzpatrick D, et al., editors. 2001. Neuroscience. 2nd edition. Sunderland, MA: Sinauer Associates.

Waring JD, Kensinger EA. 2011. How Emotion Leads to Selective Memory: Neuroimaging Evidence. Neuropsychologia 49(7): 1831-1842.