Bachelor Degree Project

The role of the amygdala in emotion and memory

Bachelor Degree Project in Cognitive Neuroscience
15 ECTS
Spring 2011

Darun Jaf

Supervisor: Daniel Broman
Examiner: Judith Annett

The role of the amygdala in emotion and memory
Submitted by Darun Jaf to the University of Skövde as a final year project towards the degree of B.Sc. in the School of Humanities and Informatics. The project has been supervised by Daniel Broman.

Date 2011-06-14

I hereby certify that all material in this final year project which is not my own work has been identified and that no work is included for which a degree has already been conferred on me.

Signature: _____

Abstract

Not so long ago the amygdala was an ambiguous region of the brain. Nowadays it is assumed that the amygdala is playing a key role in emotions, especially in the perception of fear. The amygdala is a very crucial component that enables humans and animals to detect and to respond to threats. When the amygdala is damaged the ability to learn and respond to threats becomes impaired. This paper reviews data that highlights internal processes of the amygdala as well as amygdala processes. Further, it presents amygdala processes and how the amygdala contributions to fear related emotions and memory. Additionally the paper exams what the cost are to the concept of fear in humans and animals when the amygdala is damaged. In sum, a variety of studies conducted on both humans and animals, using fear conditioning in their experiments and brain imaging machines has confirmed the importance of the amygdala in the perception of fear.

Key words: amygdala, emotions, fear, fears conditioning, memory, perception.

Table of content

Introduction

The amygdala is a small almond-shaped area in the brain consisting of grey matter, and it is an important component of the limbic system. It is located in the anterior portion of the temporal lobe, and it is occupying a volume of approximately 0.3% of the human brain (Schumann, Bauman, & Amaral, 2011). Fundamentally it is believed to play a crucial role in conditions that are relevant to fear in general. Studies on subjects with amygdala damage in both humans and animals have resulted in great findings about the contribution of the amygdala to fear related emotions and memories (Phelps & LeDoux, 2005). A brief presentation given below about the role of the amygdala, mostly based on experimental studies will shed light into the importance of the amygdala. According to for example Whalen and colleagues (1998), the amygdala is believed to monitor emotional stimuli non-consciously. This was demonstrated in a study using functional magnetic resonance imaging (fMRI) on human participants during an emotionally fearful and happy face recognition task (Whalen, et al., 1998). This can be interpreted as that the amygdala might be active even when we are not aware of fearful stimuli. Another study on healthy human participants using fMRI during a fear conditioning task demonstrated amygdala activity in the acquisition and extinction of fear (LaBar, Gatenby, Gore, LeDoux & Phelps, 1998). Further, bilateral damage to the human amygdala impairs the recognition of emotionally facial expressions (Adolphs, Tranel, Damasio, & Damasio, 1995). Thus both healthy participants and patients with amygdala damage points at the involvement of the amygdala in fear related conditions. Additionally, the amygdala is involved in storing long-term memories that are related with fear (Aggleton, 2000). The amygdala is able to modulate memory storage of conditions that are related with fear by enhancing the long-term-memory consolidation (Aggleton, 2000). To continue with memory the amygdala is also believed to be critical in fear learning and the ability to create fearful memories (Sigurdsson, Doyere, Cain & LeDoux, 2007). Further during amygdala damage it has also been noted that the ability to recognize fearful faces becomes impaired in humans (Adolphs, 2008).

Difficulties in studying the amygdala

Unlike animal studies investigating the amygdala in humans is limited because of numerous different reasons (Phelps & Anderson, 1997). A great way to study the human brain and its correlates to behavior has been and is through lesion studies (Aggleton, 2000). However, to be able to draw strong conclusions the lesions have to be restricted, and in case of the amygdala finding subjects with pure amygdala damage is very limited (Phelps & Anderson, 1997). Moreover, there are some difficulties in studying the amygdala using imaging techniques (Phelps & Anderson, 1997). The amygdala is very small, which makes it difficult to be studied even with modern imaging techniques such as positron emission tomography (PET). Furthermore, using functional magnetic resonance imaging (fMRI) which is very loud might affect the amygdala activity ending with irrelevant data representation. The loud noise coming out from an fMRI machine can scare and make the participants uncomfortable, which in turn affects the amygdala activity. Further, drawing conclusion based on imagine machines requires knowledge about the brain area that might be active during a specific task, the knowledge of the range of tasks that activates an area, and the kinds of tasks that do not activate that area (Aggleton, 2000). Furthermore, ethical concerns both on humans and animals, although less concerned on animals restrict the authorization to conduct experimental studies (Phelps & Anderson, 1997). However, there is much revealed about the amygdala and its main contributions to fear related emotional memory and the evaluation of emotional stimuli.

Aim of paper

The contributions of the amygdala are investigated in this review, highlighting on how the amygdala processes and contributes to fear related emotions and memories. Additionally what the costs are when the amygdala is damaged unilaterally and bilaterally. Further to what degree do humans and also animals lose the ability to feel fear during amygdala damage and how intense the amygdala has to be damaged will be focused on. Another important factor that will be observed is about the consequences to perception and cognition of the subjects

with unilateral and bilateral damage. These are the main aspects that will be examined in light of numerous different research areas in the field to specifically finding out amygdala involved in fear.

The limbic system and amygdala

Not so long ago it was widely believed that the limbic system was the main area in the brain involving in the neural systems of emotion. But further research has shown that the hypothesis made above was mainly because of the amygdala being included in the limbic system (Aggleton, 2000). Furthermore both functionally and anatomically the limbic system has been questioned concerning on its involvement in emotions (LeDoux, 1994). Anatomically the limbic system has confronted difficulties in mapping its area precisely, and functionally it cannot explain how emotions occur in the brain (Aggleton, 2000). It was Kluver and Bucy in 1937 during a study about the consequences of temporal lobe lesions that discovered the involvement of the amygdala in emotions (e.g. Aggleton, 2000; LeDoux, 2007). They found out that visual objects lost their emotional implications when the amygdala was damaged; this is now more referred to as the Kluver-Bucy syndrome. The Kluver-Bucy syndrome does not impair the detection of objects but rather their psychological meanings, for instance monkeys with Kluver-Bucy syndrome tried to eat uneatable objects, was not afraid of things that could scare them at earlier points, and they tried to have sex with the opposite sex or even with other species (Aggleton, 2000: LeDoux, 2007). However, it was rather a study conducted by Weiskrantz in 1956 that pinpointed the amygdala as the key area that produces emotional changes (see Aggleton, 2000). Weiskrantz in his study designed to measures avoidance conditioning, when he subsequently found out that, when the amygdala is damaged fear avoidance is impaired. Thus this small almond shaped region in the medial temporal lobe is believed to be the key to fear pathways (LeDoux, 1998). Fear in general is the emotion that has mostly been associated with the amygdala.

Anatomy of the amygdala

Anatomically the amygdala similar to most of the other brain regions consists of distinct subareas or nuclei. These nuclei in the brain as those parts of the amygdala are distinguished by analyzing their histological features, such as the density, configuration, shape and size of stained cells, the trajectory of fibers and the chemical signatures (LeDoux, 2007). Further every nuclei in the amygdala is involved in particular sorts of inputs and outputs (LeDoux, 1998). The lateral nucleus of amygdala (LA) is mainly receiving inputs to the amygdala from sensory systems such as the visual, auditory, somatosensory, olfactory and taste systems (LeDoux, 2007). Another important subarea is the central nucleus of the amygdala (CE), which is involved in the outputs of at least expression of innate emotional responses and related physiological responses (LeDoux, 2007). Expressions of these responses involve connections from the medial subdivisions of the CE to the brainstem regions, which are in control of particular behaviors and physiological responses, for instance controlling emotional responses such as freezing when confronted with danger (LeDoux, 1998, 2007; Schafe, Nader, Blair & LeDoux, 2001). A second major getaway connection of the amygdala is from the basal nuclei. The basal nucleus is connected with the CE and also the striatal areas. The striatal areas are involved in controlling actions like escaping away from danger (LeDoux, 2007). However, the major inputs are received through the LA and outputs are leaving through the CE. The main connections linking these two areas are from the medial part of the LA to other amygdala nuclei, which in turn connect with the CE (LeDoux, 2007). For instance the CE can receive inputs from the LA, and also through the basolateral and basomedial nuclei (LeDoux, 1998, 2007).

Fear Conditioning

There is so much that has been discovered about the amygdala lately by investigating the neural basis of fear with various different approaches. A well accepted approach is fear conditioning where studies of this kind have given significant and detailed understanding of

the importance of the amygdala in fear related emotions and memories. Fear conditioning is a procedure where a neutrally conditioned stimulus (CS) is paired up with an aversive unconditioned stimulus (US), (LaBar, LeDoux, Spencer & Phelps, 1995). A classic CS is for instance a tone or a light, and a US is often an electrical shock given to the feet (Aggleton, 2000: LeDoux, 2007). During fear conditioning a CS is paired up with a US and after several trials of pairings, when a CS is presented alone consequently it will elicit the same fearful responses as when paired up with a US (LeDoux, 1998). The fearful responses of CS when it is presented alone will be similar to when a subject is confronted with danger in real life situations such as detecting an enemy or a predator.

A common reaction when encountered with danger is freezing as well as is changes in blood pressure and heart rate; the same reactions are also encountered during fear conditioning (Aggleton, 2000). According to Aggleton these responses are neither learned nor voluntary, but rather innate species-typical responses that are triggered during threats. When confronted with threats in real life or in fear conditioning experiments, these species-typical responses will be expressed automatically. Thus during fear conditioning, when a subject is shocked electrically in association with a CS, the subject will be very likely to freeze and have changes in blood pressure and heart rate (LeDoux, 1994; Schafe, et al., 2001). Furthermore, the same reaction also occurs when the subject becomes presented with CS only. It is through synaptic plasticity in the lateral nucleus of the amygdala that the CS, when presented alone, is able to elicit the same responses as when presented with US (LeDoux, 2007). The study of rodents has contributed with mapping the connectivity between inputs and outputs of the amygdala and sub-nuclei mediating fear conditioning (Schafe, et al., 2001). It was revealed that convergence between a CS and a US ends with synaptic plasticity in lateral nuclei of the amygdala (LeDoux, 2007; Schafe, et al., 2001).

Single unit studies have demonstrated that cells in the LA have the properties needed for synaptic plasticity, and also that the LA is highly involved in fear conditioning (LeDoux, 2007; Aggleton 2000). The same cells in the LA also receive inputs about the (US) electrical charge given to the feet (LeDoux, 2007). Further the cellular response to the CS becomes

extremely enhanced (more action potentials are elicited), when the CS and the US are paired (LeDoux, 2007; Aggleton 2000). These findings in single unit recording studies explain how the CS when presented alone can elicit the same responses as when presented with the US (LeDoux, 2007). The importance of the lateral nucleus and the central nucleus of the amygdala in fear conditioning is shown to be crucial in learning and responding to conditioned fear. Because when the lateral amygdala is damaged the ability to acquire and express previously learned fear becomes impaired and when the central amygdala is damaged the ability to respond to fear will become impaired during fear conditioning (Schafe, et al., 2001). Jimenez and Maren (2009) in a study on rats demonstrated the importance of the basolateral complex (BLA; basal and lateral nuclei of the amygdala) and the central nucleus of the amygdala (CE) in fear conditioning. During which, experimental rats (n, = 11) received asymmetric neurotoxic lesions of the BLA and CE, where lesions of the BLA were placed in one hemisphere and lesions of the CE was placed in the contra-lateral hemisphere. This produced a functional disconnection between the hemispheres. On the other hand, control rats (n, = 13) received neurotoxic lesions to the BLA and CE in the same hemisphere, in that way both structures and connections were still intact in that hemisphere. This strategy was used in order to find out whether the projections from the BLA to the CE are ipsilateral or unidirectional. There was also a sham group with no lesions (n, = 16). Freezing behavior of rats served as measurement during fear conditioning, during which, rats were presented with an auditory CS paired up with an electrical foot-shock US. Twenty-four hours after the fear conditioning procedure experimental and control rats received specific lesions to their BLA and CE as described above. One week after those rats in the experiment and control group had received lesions; their retention to the conditioning context and the auditory CS were investigated by measuring freezing responses. Results indicated that freezing to both conditioning context and to auditory CS become severely impaired after functional disconnection to the BLA and the CE. Fundamentally, fear expression to the auditory CS was abolished after the functional disconnection. Additionally, freezing responses among rats was significantly lower in the experiment group compared to the control and sham group during the retention session. Accordingly to Jimenez and Maren (2009), a unidirectional functional

connection between the BLA and CE is required in order to be able to express learned fear. Further, the necessity of both the BLA and the CE in fear expression arising from a functional connectivity is demonstrated.

Amygdala involvement in conditioned fear

The precision and outcomes of fear conditioning have been measured in experimental studies directly through the responses obtained from CS (LeDoux, 1998). These responses are such as freezing, suppression of ongoing behavior, pain inhibition, autonomic responses (changes in blood pressure and heart rate), endocrine responses (hormonal releasing) and potentiated reflex responses (LeDoux, 1994, 2007). Thus, fear conditioning has been shown to be a very liable experimental task, which is often used to study the role of the amygdala in conditioned fear (Aggleton, 2000). Now that the creditability of fear conditioning is settled, some experiments that examine how the amygdala is involved in fear acquisition and extinction will be presented. One study by LaBar and colleagues (1998) used functional magnetic resonance imaging (fMRI) to examine human amygdala activity during conditioned fear acquisition and extinction. Healthy human participants were separated into two groups, the task group was presented with one visual, the CS, which was paired up with an electrical shock to the wrist, the US in acquisition, and the control group was presented with CS only (LaBar, et al., 1998). Scans were acquired for both the acquisition and the extinction phases. The results showed activation in the amygdala for both the acquisition and the extinction during fear conditioning. Furthermore, in that study amygdala activation was dominant in the right hemisphere during conditioned fear acquisition and extinction. Although less influenced compared to the right hemisphere, left hemispheric amygdaloid and bilateral amygdala activation was observed on individual level during both conditioned fear acquisition and extinction. Though, the hemispheric asymmetries should be interpreted with caution (LaBar, et al., 1998). However, this study demonstrates amygdala activation in healthy humans during conditioned fear acquisition and extinction; it also demonstrates differences in hemispheric activation regarding the same matter (LaBar, et al., 1998).

Another study used fear conditioning as a model in order to investigate emotional learning and memory in human participants that had unilateral medial temporal lobe lesions (LaBar, et al., 1995). Damage in the participants was sustained to the amygdala and to the hippocampus, both associated with complex limited seizures of medial temporal lobe, but compared to amnesic patients with bilateral hippocampal lesions, these participants did not have severe declarative memory impairments (LaBar, et al., 1995). Participants were asked to take part in a simple discrimination task and in a conditional discrimination task. This was done to find out the role of the temporal lobe in simple and complex aspects of associative responding. Participants in the control group were also asked to take part in a simple discrimination and in a conditional discrimination task, but they did not have any history of seizures or neurological impairments. Participants were required to attend to sounds (also lights in the conditional discrimination task) and to try to detect a pattern due to the stimuli, which the experimenter would ask the participants to report occasionally during the session. During the simple discrimination task participants were asked to verbally describe what they heard. In the conditional task participants were also asked to verbally report what they remembered, both visual and auditory knowledge acquired during that specific session. Results from both the simple and the conditional discrimination tasks showed impaired fear conditioning in participants with temporal lobe resection. The impairments were mainly concerned with response acquisition during both simple and conditional discrimination tasks. However, it is important to note that the impairments demonstrated are related to conditioned fear acquisition, that is, the ability of a CS mediating an autonomic response after repeated pairings with an aversive US (LaBar, et al., 1995). Further, no hemispheric differences were found in neither left nor right temporal lobe damaged participants during the simple and conditional discrimination tasks. Thus, in accordance with the above mentioned studies, the amygdala appears to be crucial in fear conditioning. The involvement of the amygdala during fear conditioning studies was demonstrated through both healthy and amygdala damaged human participants. Although participants in the second study had lesions outside the amygdala the impairments to fear conditioning could be cross matched with activation of the amygdala during the first study in order to strengthen the reliability of amygdaloid

involvement.

Another study is in accordance with the ones formerly mentioned and it uses fear conditioning as well (LeDoux, Cicchetti, Xagoraris, & Romanski, 1990). This study examines the brain mechanism that is essential to the configuration of emotional association; however, this study is rather conducted on rats (LeDoux, et al., 1990). Prior to the experiments rats received anesthetics and subsequently got their LA damaged bilaterally. After the wounds were closed the rats were placed in their home cages in order to rest. After two weeks of recovery all rats participated in a fear conditioning task, where the CS consisted of a tone and the US consisted of electrical charge. During the experimental task the first 10 trials of CS were presented alone, and the subsequent 30 trials of CS were associated with US. The conditioned responses to CS were measured subsequently; the measurement included emotional behavior (freezing) and autonomic reactivity (arterial pressure) in the presence of CS. The results in the experiment demonstrated that lesions to LA reduce behavioral and autonomic responses (freezing and arterial pressure), since the thalamic projection from LA to CE becomes interrupted when LA is damaged and fear conditioning becomes impaired. Though, the lesions in this experiment on rats did not entirely impair the responses elicited by CS during fear conditioning, when compared to the control group. However, this study points at the amygdala being a key mechanism concerned with emotional learning and behavior during fear conditioning (LeDoux, et al., 1990).

The amygdala modulates memory storage

Emotionally arousing events that are experienced in extremely positive or negative manners will often be well remembered (Aggleton, 2000; Cahill & McGaugh, 1996). Experimental studies in humans and in animals suggest that experiences that are highly arousing will be remembered more accurately, more easily and over a longer period of time compared to less arousing experiences (Aggleton, 2000; McGaugh, Cahill & Roozendaal, 1996; Schafe, et al., 2001; Cahill, et al., 1996). This implies that the brain is able to select the

kind of information that will be stored for a longer time. In order for this to happen the brain has to possess a mechanism that distinguishes important information from trivial information (Aggleton, 2000; Cahill & McGaugh, 1996). Findings in human and in animal studies point out the amygdala as a liable component that influences memory storage (McGaugh, et al., 1996). Thus the amygdala is suggested to be crucial in modulating long-term-memory storage of emotionally arousing events (Aggleton, 2000). It is emotionally arousing events that activate the involvement of the amygdala, which in turn results in modulation of memory storage in brain regions (McGaugh, et al., 1996). This was demonstrated in a study by Aggleton on amygdala damaged rats, in which they failed to avoid drinking water that was paired up with electric charge, which is emotionally arousing stimulus and unpleasant (Aggleton, 2000). Though, the same interference in avoidance did not occur when the water tasted bitter, which is also an unpleasant stimulus but not emotionally arousing. Thus, the degree of emotional arousal influences amygdala involvement in learning, rather than the nature of the stimuli, whether pleasant or unpleasant does not matter (Aggleton, 2000). These suggestions have been drawn on differential animal and human studies (Aggleton, 2000). The studies have examined the factors that influence memory storage (enhance or impair) in the amygdala, such as drugs or effects of the amygdala in mediating stress hormones. Additional examinations have been focused on consequences of amygdala lesions and amygdala inactivation, measured by imaging machines such as PET and fMRI (Aggleton, 2000).

Hormonal effects on memory storage

The two hormones that are believed to mostly influence the amygdala in memory storage consolidation are norepinephrine and glucocorticoid (McGaugh, et al., 1996). These hormones influence the amygdala differently, glucocorticoid is able to enter the brain readily and activate steroid receptors, but epinephrine on the other hand passes through the blood brain barriers very poorly, if at all, which ends in indirect mediated effects on memory (McGaugh, et al., 1996).

Epinephrine

Electrical stimulation of the amygdala is able to either enhance or impair the modulation of memory storage (McGaugh, et al 1996). One factor that can change the effects of electrical stimulation of the amygdala on memory storage is injection of epinephrine. Experimental studies have demonstrated the role of epinephrine on memory storage, during which, when rats were induced with epinephrine prior to training tasks the effects subsequently enhanced memory storage (McGaugh, et al., 1996). Further evidence in light of the role of epinephrine was found in inhibitory avoidance training experiments on rats with amygdala damage, which resulted in blockage of epinephrine effects (McGaugh, et al., 1996). Additionally the effects of epinephrine are also blockaded by B-adrenergic antagonist propranolol infused into the amygdala directly after training and directly prior to the peripheral epinephrine injections. The B-adrenergic blockers infusion into the amygdala resulted also in findings about the importance of norepinephrine (NE), (McGaugh, et al., 1996). It is believed that NE release in the amygdala plays an important role in mediating the effects of epinephrine on memory. Furthermore it is suggested that post training infusion of NE into the amygdala should modulate memory storage. This involvement of NE was supported during foot-shock stimulation in inhibitory avoidance training tasks, which ended in a remarkable increase of NE release in the amygdala (McGaugh, et al., 1996). Considered together these findings support the view that the amygdala is important in mediating the effects of epinephrine on memory storage, and that NE release within the amygdala is highly involved, when the amygdala mediates epinephrine effects on memory storage (McGaugh, et al., 1996).

Glucocorticoid

The influences of glucocorticoid on memory storage are drawn on evidence indicating that activation of adrenal steroid receptors in the hippocampus plays an important role in mediating effects of glucocorticoid on memory storage (McGaugh, et al., 1996). Laboratory research has also demonstrated glucocorticoid affects on memory storage through amygdala

influences (McGaugh, et al., 1996). The effects of glucocorticoid on memory storage in inhibitory avoidance training task on rats are similar to those of epinephrine (McGaugh, et al., 1996). For instance amygdala lesions restricted to basolateral nuclei impairs enhancement effects of glucocorticoid on memory storage. Furthermore, the enhancement of memory was demonstrated in a study on rats, when glucocorticoid was infused into the basolateral amygdala (McGaugh, et al., 1996). It resulted in retention enhancement; however, the infusion administered into the CE was ineffective. Thus the effects of glucocorticoid in memory modulation are not mediated through CE (McGaugh, et al, 1996). Additionally, the effects of glucocorticoid in memory modulation similarly to epinephrine, involve activation of NE within the amygdala (McGaugh, et al., 1996). The conclusions drawn above about the adrenal hormones in mediating memory storage and about the fact that such effects involve amygdala influences are drawn on rat studies. However, there are also human studies that are consistent with this view as well, and below three of these are discussed (McGaugh, et al., 1996).

Hormonal effects on human memory storage

The first study presented here examined the effects of the B-blockers propranolol and placebo on long-term-memory for either an emotionally arousing story or a similar but rather emotionally neutral story (McGaugh, et al., 1996). The participants were healthy human volunteers that viewed a 12-slide story accompanied by narration, where the emotionally arousing narration comes about in the middle of the story. As predicted the placebo group had enhanced memory for the emotionally arousal story, compared to the propranolol group which had selectively impaired memory for the emotionally arousal story. The impairment of the propranolol group did not affect the neutral story. Important to note, the effects of propranolol did not impair attention or emotional responsiveness to the stories; neither did propranolol have any sedative effects on participants. This study demonstrates and supports the view that modulation of memory storage by emotionally arousal events depends upon activation of B-

adrenergic receptors (McGaugh, et al., 1996).

A second study examined the association between amygdala activity and the long-term-memory storage of emotionally arousing events (Cahill, et al., 1996). The association was measured by investigating the cerebral glucose metabolism in the amygdala with positron emission tomography (PET) during emotionally arousing events (Cahill, et al., 1996). Eight healthy participants were recruited for this study, during which they observed two videos. Each video consisted of 12 film clips, which were presented as stimuli during the PET sessions. The videos were divided into two categories one composed of emotionally neutral film clips (N) and the other of emotionally arousing film clips (E). The participants viewed both kinds of the videos, and every participant completed two PET sessions. Participants were contacted by phone three weeks after the second PET session, and they were asked to recall as much as possible about both videos. As predicted participants recalled more E films compared to N films (Cahill, et al., 1996). Additionally, a correlation between glucose metabolic rate of the right amygdala activity and emotional films recalled was found as well. Furthermore, support is found for amygdala activation during emotional experiences related to conscious recall of those specific experiences; however, there was no activation during non emotional conscious recall or learning.

The third study consists of three different experiments, with the aim to examine amygdala involvement in processing stimuli concerned with emotional arousal (Aggleton, 2000). The first experiment investigated amygdala involvement in emotional arousal and valence (Aggleton, 2000). Participants were 24 healthy controls and a female participant (S.M) with bilateral amygdala damage. Participants were asked to rate, on a nine-point scale, emotional face expressions based on their valence (pleasantness/unpleasantness), and arousal on a nine-point scale.

Before the task, participants were informed about the nine-point rating scale procedure, where in the valence scale ratings above 5 indicated stimuli that were more pleasant than neutral, and ratings below 5 indicated stimuli that were less pleasant than

neutral. Also, in the arousal rating task, rating above 5 indicated higher arousal (energy and wakefulness) and rating below 5 indicated lower arousal (sleepiness and relaxation) compared to normal arousal states. The rating results from the valence of emotional facial expressions of S.M compared to controls were normal; results were within 2 SDs (Aggleton, 2000). However, she was severely impaired in ratings of arousal for specific emotional facial expressions; she differed from the control mean by more than 4 SDs in rating negative emotions of fear and anger. However this impairment in rating arousal concerned with unpleasant emotions only, and not pleasant ones. The second experiment with S.M and 18 healthy control participants examined arousal and valence, where participants were asked to rate stories with emotional indication (Aggleton, 2000). Results demonstrated that S.M had severe impairments in recognizing arousal in stories and words related to negative emotions, in which she rated anger and fear as rather relaxing. She succeeded in rating some fearful stories with the right emotion, but her ratings were far from the control ratings, she did not seem to find these highly negative arousal stories as terrifying as did the controls. However, similar to the former task her ability to rate valence to all emotions was normal (Aggleton, 2000).

The last and third experiment presented S.M with stimuli and subsequently asked her to describe how those stimuli made her feel (Aggleton, 2000). This experiment provides information about her emotional experience unlike the previous ones. The stimuli presented to her consisted of brief clips from movies that elicit negative emotions. The clips were used from Gross & Levenson 1995, and which had been shown to be very effective in eliciting emotional experiences in participants (Aggleton, 2000). She was able to rate negative valence normally when presented with clips that elicit anger, disgust or sadness, and these clips received the highest negative ratings possible (Aggleton, 2000). However, she rated clips concerned with emotional arousal as rather neutral. On the other hand, her ability in rating clips that usually elicit fear was impaired on both valence and arousal; she rated those fearful clips as neutral (5 on the nine-point scale related with both valence & arousal) as well. Further, when she was asked to describe how she felt emotionally when she was watching

those movies, she replied “neutral”, but; she mentioned that most people watching these kinds of movies would become afraid. It appears that S.M has an incomplete concept of fear particularly with the knowledge that fear is highly arousal. This impairment could be a key correlate concerned with the ability to detect potential danger (Aggleton, 2000). Furthermore, her impaired ability to recognize facial expressions of fear and the results collected from the experiments mentioned above are both in favor of amygdala involvement in memory modulation of emotionally arousing events (Aggleton, 2000). These results, based on previous animal and human investigations, support the view that the amygdala is involved in arousal related learning and memory processing (Cahill, et al., 1996; Cahill, & McGaugh, 1996; McGaugh, et al., 1996; Aggleton, 2000). Thus fundamental support in humans as well as in animals is available the in light of amygdala involvement in modulating memory storage of emotionally arousal events (Cahill, et al., 1996; Cahill, & McGaugh, 1996; McGaugh, et al., 1996 Aggleton, 2000).

Amygdala involved in fear recognition and detection

The amygdala has been associated with recognition of emotional expressions especially with fear related expressions (Adolphs, et al., 1995). It is suggested that lesions to the human amygdala result in impaired recognition of fearful faces (Adolphs, et al., 1995). Results from several different studies on amygdala lesions support the view that the amygdala is involved in the recognition of emotional stimuli. One study with interesting findings investigated the consequences of bilateral and unilateral (right and left) independent amygdala lesions and also the extent to which the lesions were associated with facial fear expression (Adolphs, et al., 1995). Participants in this study were divided into different groups; one female participant (SM-046) with bilateral amygdala damage, three with unilateral left amygdala damage and three with unilateral right amygdala damage. These participants were compared with 19 control subjects, 12 of them had damage to the brain but had an intact

amygdala and 7 had no history of either neurological or psychiatric diseases. The experimental task demanded participants to recognize facial expressions of emotions. The facial expressions presented on a screen to the participants included faces of happiness, surprise, disgust, fear, anger, sadness and also three neutral faces. The results demonstrated that SM-046 had the highest impairment in judging the intensity of fear and expressions similar to fear such as surprise, when compared to participants with unilateral amygdala damage and controls (Adolphs, et al., 1995). This suggests that bilateral damage and not unilateral damage impairs judgments and recognition of fear expressions. Furthermore, it was revealed that SM-046's impairment was not limited to visual perception only but also to visual imagination related to emotional meaning. Immediately after the exposition to the facial expression task, SM-046 was asked do draw pictures of facial expressions from memory. SM-046 was able to draw facial expressions without any difficulties except for fear; she was completely unable to draw expressions of fear, and it appears that SM-046 did not experience fear normally. It was considered that SM-046 can perceive visual features of faces normally and connect that perception with her knowledge in order to recognize familiar persons. But, she could not execute the same procedure when certain facial emotions were involved particularly the expression of fear. However, these results did not imply that SM-046 lacks the concept of fear (Adolphs, et al., 1995). When interviewed she was able to describe situations that can evoke fear and in which scared people tend to react with fear (Adolphs, et al., 1995; Aggleton, 2000). Although the conclusions made in the above mentioned experimental study were based on comparison between three left and three right unilateral amygdala damaged participants and one bilateral amygdala damaged participant, much was revealed about the importance of bilateral amygdala involvement in fear detection, recognition and imagination (Adolphs, et al., 1995). It is also revealed that bilateral amygdala damage, as with SM-046, might leave many aspects of fear intact in humans, such as verbal

description of fear or to some extent the ability to decide whether a person may be expressing fear or not, probably by reasoning from prototypical features known to her that go together with fear for instance wideness of eyes (Adolphs, et al., 1995). However, SM-046 cannot link the perception of expression with knowledge that would let her determine the intensity of fear (Adolphs, et al., 1995). Fundamentally it is suggested that bilaterally the amygdala is fundamental to both the recognition and the retrieval of comprehensive knowledge related to the concept of fear (Adolphs, et al., 1995). Aggleton (2000) argues that impaired fear recognition, as in the mentioned data above and the data presented below, is a consequence of damage to a more universal neural system in charge of emotional recognition that in turn detects potential harm to the organism, which includes anger and fear. This hypothesis was drawn based on the above mentioned data and further examination on SM-046 as well and other participants with bilateral amygdala damage (Aggleton, et al., 2000). In one task SM-046 was asked to give spontaneous descriptions of emotions in faces shown to her with one word (Aggleton, et al., 2000). Compared to normal controls she was impaired in naming fear, and she never used the label of fear. In a different task, emotionally morphed faces were joined into a scrollable movie (neutral-happy-surprise-afraid-angry-disgust-sadness-neutral) which SM-046 could move forwards and backwards (Aggleton, 2000). The task required her to scroll through the images until they had changed to another emotion and then confirm where the changes occurred. She was able to accurately select happiness, surprise and sadness, but she missed the fear category entirely, confused some fear faces with anger, and confused some of the angry and all of the disgusted faces with frustration. This method revealed where her emotion category boundaries and prototypes are located (Aggleton, 2000). Additional data collected from healthy controls and bilateral amygdala damaged participants demonstrated that happy face recognition was performed most consistently among all participants, whereas bilateral amygdala damaged participants were severely impaired in the

recognition of fearful faces, compared to controls (Aggleton, 2000).

Dellacherie, Hasboun, Baulac, Belin and Samson (2011) demonstrated that unilateral amygdala damage impairs the ability to detect and recognize fear in voices as well. This impairment in fear recognition unlike the previous ones mentioned above is rather concerned with recognition of voices and not recognition of facial expressions. Participants in this study had either left (n = 10) or right (n = 8) medial temporal lobe resection (Dellacherie, et al., 2011). Further, participants with complete unilateral amygdala damage (8) was differentiated from participants with basolateral complex amygdala damage (10), the separation was done after fMRI scanning on the participants. This was done in order to find out more about the role of amygdala subareas. Nonverbal vocalization expressing anger, disgust, fear, happiness, sadness, surprise and neutral, 10 for each category was presented as stimuli to the participants. Experimenters assured that the participants in the study understood the meaning of the presented emotional stimuli to them before the task. The nonverbal vocalizations were presented by 5 male and 5 female actors, instructed to produce short emotional interjections. Subsequently participants rated every stimuli presented to them. First participants were required to rate the intensity of the emotions produced by the actors , ranging from not at all to extremely intense, second they rated the valence of stimuli, ranging from extremely negative to extremely positive, and at last the arousal of stimuli from not at all aroused to extremely aroused. Results from the current study indicate that the amygdala is a key structure underlying the recognition of fear in voices. As participants in the voice recognition task with unilateral temporal lobe resection were selectively impaired in recognizing fear and also surprise, when compared to healthy control participants. The impairment of recognition was mainly concerned with fear and surprises, recognition of the other emotions were unimpaired, indicating that lesion to the amygdala does not end with a general emotion deficit. Further, the separation of participants with complete from incomplete amygdala lesion revealed that the

basolateral complex of the amygdala is critical to the recognition of fear. LeDoux, (2000) has also indicated and demonstrated the importance of the basolateral complex of the amygdala in fear recognition, although the results were based on animals. However, it is important to note that lesions to participants in the current study included the hippocampus and surrounding structures as well. This makes it difficult to exclude the contribution of the hippocampus to the emotional processing.

These data presented here propose that the human amygdala is a component of a neural system that is specialized to rapidly trigger physiological states related to stimuli that indicate danger or threat (Aggleton, 2000). Further, the role of the amygdala in fear recognition is not limited to only facial expression, it extend to recognition in voices as well supporting the multimodal role of the amygdala.

The amygdala during emotional processing and learning

The amygdala can process fear related information non-consciously. Studies on the human amygdala has provided data that confirm amygdala involvement during fear perception and fear related learning, without awareness and any explicit knowledge of presented stimuli (see Aggleton, 2000). This was demonstrated in a study where the affects of attention on amygdala processing of fear was investigated (Anderson, Christoff, Panitz, & Rosa, Gabrieli, 2003). Event-related functional magnetic resonance imaging (fMRI) was used on 12 healthy human participants (9-women & 3-men) to measure brain activity during presentation of neutral, fearful, or disgusted facial expressions (Anderson, et al., 2003). Results related with attention on human amygdala responses demonstrated a discrete activation in the right amygdala. This was confirmed when participants attended to fearful face expressions compared to neutral and disgusted face expressions. Additionally, during

inattention amygdaloid activity to fearful faces was greater when compared to neutral faces. Furthermore, amygdaloid activity increased significantly in responses to disgusted facial expressions during unattended relative to attended conditions. Surprisingly, during inattention amygdala activity was rather greater for disgusted face expressions compared to fearful face expressions. However, inattention did not remarkably reduce amygdala responses to fearful face expressions; it rather enhanced amygdala responses to disgusted face expressions. Furthermore, automatic processing in the amygdala is rather specific to social signs of fear, but that procedure is not entirely automatic (Anderson, et al., 2003). Since the amygdala become highly responsive to facial expressions of disgust during inattention, more than to facial expressions of fear. Thus, according to these findings the amygdala appears to be limited in encoding facial features automatically (Anderson, et al., 2003). The automatic processing is not specific to fearful faces only; it may be rather limited to various features of faces, for instance the degree of arousal or valence in facial expressions (Anderson, et al., 2003). These findings supports the view held by LeDoux (1996), that the amygdala has two parallel pathways, one sub-cortically mediated and one cortically mediated (Anderson, et al., 2003; LeDoux, 1996). The sub-cortical (shorter thalamo-amygdala) pathway process information automatically and quickly, while the cortical (longer thalamo-cortical-amygdala) pathway processes more detailed information, though the processing is rather slow and attention dependent (Anderson, et al., 2003; LeDoux, 1996). The reduced ability to analyze and resolve responses to stimuli during inattention (shorter thalami-cortical pathway) is interpreted as a consequence of the amygdala being limited in processing information completely (Anderson, et al., 2003). However, resolving environmental threats (detect a snake) rapidly and acting in response to that threat is more crucial than recognizing false alarms (not a snake) which requires slower and more detailed processing (Anderson, et al., 2003). Thus during reduced attention the amygdala in healthy humans does not respond to all

kinds of stimuli completely as in a attended condition, rather it extends its responds to significant features of potential threats (Anderson, et al., 2003). Important to note that gender differences are believed to affect amygdala responding to stimuli, further investigation with larger and more balanced sample is required, as the current study had more female participants than male participants (Anderson, et al., 2003).

In another study, human amygdala activation was once again demonstrated during presentation of stimuli in absence of explicit knowledge (Whalen, et al., 1998). Healthy participants (10 male) were examined with fMRI during presentation of backward facial expressions. During the task participants viewed a movie clip on a screen consisted of presentation of a cross (+) as fixation point, and presentation of either fearful faces masked by neutral faces or happy faces masked by neutral faces. In order to find out that the emotional faces (fear and happy) presented to participants were not detected, they were asked to describe aspects of faces they saw during the movie. Eight of 10 participants reported that they had only seen neutral faces; the remaining two showed indication of seeing emotional target stimuli, for that reason their data were excluded. Results from the remaining eight subject's demonstrated Blood oxygen level-dependent (BOLD) fMRI signal bilaterally in the amygdala, which were significantly higher in response to masked fearful faces compared with masked happy faces. Activation increased in the amygdala for fearful face expressions and decreased for happy face expressions. Findings from this experiment as well demonstrate isolated amygdala activity when responding to fearful stimuli without explicit knowledge. The findings are also in accordance with LeDoux (1996), that the amygdala is able to process information in absence of explicit knowledge (Whalen, et al., 1998). Important to note that the current experiment and its results are based on male participants only, further investigation with larger and more balanced sample is required in order to generalize absolute data. However, comparing results from both studies it can be well established that the human

amygdala is playing a crucial role in automatic processing during detection of potential harm in face expressions of fear and disgust, in absence of explicit knowledge (Anderson, et al., 2003; Whalen, et al., 1998). Furthermore, an important factor that influences the automatic processing of the amygdala is the degree of arousal and valence (Aggleton, 2000; Anderson, et al., 2003; Whalen, et al., 1998).

Additional support for amygdala activation, and importantly for a direct shorter pathway is demonstrated in a study using fMRI on healthy humans (Liddell, et al., 2005). Prior to the experiment in this study, it was hypothesized that humans and animals are able to respond to danger rapidly and reflexively through a direct path way relying on basic and necessary information. Patients with blindsight, which cannot consciously see visual stimuli on their blind visual field demonstrated amygdala modulation and also activation in other brain regions such as the pulvinar and striate cortex, when presented with fear related stimuli (Liddell, et al., 2005). These findings on patients with blindsight demonstrate areas that might be involved in the direct path way to the amygdala, involving fear detection without awareness. In order to examine this network underlying detection of fear related stimuli without awareness, focus was attended on various relevant brain areas, brainstem, thalamic pulvinar, amygdala and anterior cingulated areas (Liddell, et al., 2005). Healthy human particip,ants (11 male and 11 female) where presented with fearful and neutral face stimuli for 10, 20, 30, 40 and 50 ms with backward masking by neutral stimuli for 100 ms. Results from fMRI demonstrated significant activation in the brainstem, left pulvinar, bilateral amygdala and bilateral anterior cingulated, during presentation for fearful stimuli in absence of explicit knowledge. Further, the right amygdala was more activated compared to the left amygdala. Taken together activation in the mentioned brainstem regions above suggests that those areas might provide with an alternative direct path way to the amygdala (Liddell, et al., 2005). Where the amygdala receives rapid and basic fear related sensory information through this

pathway without conscious awareness.

Gender differences and lateralization

As mentioned in a previous section the amygdala is highly involved in the modulation of emotionally arousing events, however, it is believed that the amygdala is activated differently in men and women (Wager, Luan Phan, Liberzon, & Taylor, 2003). Meta-analysis on 65 PET and fMRI studies of emotional tasks from 1992-2002, supports the view about amygdala lateralization (Wager, et al., 2003). Suggesting that men are right and female are left lateralized, in the amygdala. Further, evidence from brain imaging has demonstrated differences in amygdala lateralization between men and women during the process of emotionally arousing events (Cahill, Uncapher, Kilpatrick, Alkire, & Turner, 2004). The study by Cahill, et al., (2004), demonstrated amygdala lateralization during an fMRI study on healthy humans. Twelve males and 11 females participated, however, eight of them (4 men and 4 female) were excluded from the imaging analyses due to drop outs. The remaining participants were presented with 96 slide scenes, and subsequently were asked to rate the emotional arousal of scenes by pressing a lever after the scene had disappeared. During the rating of emotionally arousal scenes, participants could chose from a four level rating scale, where 1 indicated not emotionally arousing and 4 indicated highly emotionally arousing. The evaluations made by participants were recorded by experimenters. Two weeks after the fMRI scan, participants conducted an unexpected recognition test, in which they were asked to recognize the previously presented pictures plus 48 new pictures closely matched to the previous ones. No gender differences were found for the recollection of false pictures, further, women rated pictures as more highly arousing when compared with men. Though, men had a better retention of highly arousing pictures then women did, and men was more certain in retention of pictures rated as highly arousing then women. Results of between-group analysis from the fMRI scan revealed that, women had significant left hemisphere amygdala blood

oxygen level-dependent (BOLD) activity during rating pictures as emotionally arousing and during their retention (Cahill, et al., 2004). Men on the other hand had significant right hemisphere amygdala BOLD activity during rating pictures as highly arousing and during their retention. Further, independent analysis in men and women demonstrated significant activation clusters in the right hemisphere amygdala but not the left for men, and the left hemisphere amygdala and not right for women. Thus both independent and between group results demonstrates amygdala lateralization and differences of amygdala activation in men and women, during rating for emotionally arousing pictures (encoding) and during long-term memory retention (Cahill, et al., 2004). Further, these results does not exclude left amygdala involvement in men and right amygdala involvement in women, rather demonstrates a significant lateralization for at least the kind of task performed in this experiment (Cahill, et al., 2004). Additionally, the results concerned with amygdala lateralization are related to long-term memory for emotionally arousing events. Further, the lateralization demonstrated here in the human amygdala is related with emotionally negative arousal and not emotionally positive arousal. However, this study is in accordance with previous suggestion mainly made from the meta-analysis paper by Wager and colleagues (2003) and with other individual experiments, concerning amygdala lateralization depending on the gender in humans.

Discussion

Taken all together, the data presented above suggest that the (human and animal) amygdala is a component of a neural system that is specialized to rapidly trigger physiological states related to stimuli that indicate danger or threat (Aggleton, 2000; Rosen & Donley, 2006). This hypothesis has been demonstrated and confirmed in a variety of experimental studies on humans and animals. It started with Kluver and Bucy (1937) during a study about the consequences of temporal lobe lesions, where they revealed amygdala involvement in emotions (e.g. Aggleton, 2000; LeDoux, 2007). Approximately 20 years later, Weiskrants

(1956) in a fear conditioning study pin-pointed the amygdala as a key area that produces emotional changes. Studies on the amygdala in humans and animals have grown from that point on. Fundamental support was found when it was confirmed that the amygdala was a key mechanism involved with emotional learning and behavior during fear conditioning (LeDoux, et al., 1990). Because when the amygdala became damaged behavioral and autonomic responses were impaired during fear conditioning in humans and animals. Further, two specific nuclei in the amygdala were pin-pointed as key nuclei during fear conditioning, the LA which is receiving information from the cortex and the CE which is viewed as the controller of the brainstem, where it coordinates behavioral, autonomic and neuroendochrine responses (Pessoa, 2011). The importance of the LA and the CE in fear conditioning has been shown to be crucial in learning and responding to conditioned fear. Because when the LA is damaged the ability to acquire and express previously learned fear becomes impaired and when the CE is damaged the ability to respond to fear will become impaired during fear conditioning (Schafe, et al., 2001). These findings strongly indicate that the amygdala is a key structure that is necessary for humans and animals in everyday life in order to be able to avoid and behave when confronted with threatening situations. This is also in accordance with Aggleton implying that the main function of the amygdala is to predict and react to threats. Where, he has demonstrated the involvement of the amygdala and the consequences of amygdala damage in a variety of experimental studies on patients with lesions covering the amygdala in his own laboratory (see Aggleton, 2000).

Experimental studies on the amygdala have flourished since its importance (concerned with emotions and learning) in fear conditioning has been confirmed progressively. From that point on, great findings have been made about amygdaloid involvement besides fear conditioning. Among them is amygdaloid involvement in the modulation of memory storage, where the amygdala influences the modulation of memory storage for emotionally arousing

events (McGaugh, et al., 1996; Kensinger, Addis, & Ataputtu, 2011). Studies on humans and animals confirms that the amygdala is involved in arousal related learning and memory processing (Cahill, et al., 1996; Cahill, & McGaugh, 1996: Aggleton, 2000). Thus, the amygdala in this case and not the hippocampus is crucial in order for humans and animals to be able to store emotionally arousing information. As patients with damage to the amygdala and not the hippocampus, are impaired in storing and retrieving emotionally arousing information. Additionally damage to the amygdala does not only impair the ability to store relevant information into long-term memory but also affects the concept one has of fear in general. Since, amygdala involvement has been demonstrated during the recognition and detection of fearful face expressions, particularly fearful face expressions (Adolphs, et al., 1995). However, the role of the amygdala in fear recognition is not limited to only facial expression, it extend to recognition in voices as well, supporting the multimodal role of the amygdala (Dellacherie, et al., 2011). Thus, the amygdala is critical in humans and animals in order to be able to recognize and detect fear in general. These findings are also in accordance with the belief shared by LeDoux (1996), that the amygdala is the core region in the brain that contributes with a general perception of fear.

Moreover, gender differences and lateralization in the amygdala have been demonstrated in experimental studies, where it has been shown that the amygdala is activated differently in humans (Wager, et al., 2003). Suggesting that men are right and females are left lateralized in the amygdala during the procedure of emotionally arousing events (Cahill, et al., 2004). This is a rather undeveloped assumption of the amygdala and needs further research with more specified experimental studies conducted on larger group of participants before it can be established.

Information reaches the amygdala through two parallel pathways, one sub-cortically mediated and one cortically mediated (Anderson, et al., 2003; LeDoux, 1996; Öhman, 2005).

The sub-cortically mediated pathway is able to processes information automatically and rapidly (non-consciously), though the information is rather poor but enough to detect threats and to react in threatening situations. The cortically mediated pathway is rather slower and is dependent on awareness (consciousness), though the information is much more detailed. The sub-cortically mediated pathway enables humans and animals to resolve environmental threats (detect a snake) and act to that threat rapidly. Thus during reduced attention (unconsciousness) the amygdala in healthy humans does not respond to all kinds of stimuli completely as in a attended condition (consciousness), rather it extends its responds to significant features of potential threats. One way to confirm this further is by examining the pathways one by one through brain scanning machines and through patients with lesions. Although finding human patients with such specific lesions might sound impossible, researchers can begin with animals, which, have contributed with great findings in the field.

Fear is the function that has mostly been associated with the amygdala, though there are several other functions that might be linked and dependent on the amygdala to some degree. Studies have beside the emotion of fear observed amygdala involvement in aggressiveness, maternal, sexual and in eating and drinking behaviors. Although, data about these functions associated with the amygdala requires further experimental research before any concluding remarks can be drawn. Moreover, the amygdala is also believed to modulate cognitive functions, such as attention, perception and explicit memory (LeDoux, 2007; Aggleton, 200). Accordingly external emotional stimuli being processed by the amygdala modulates those cognitive functions. Further, the amygdala has also been associated with a variety of neuropsychiatric/neurodevelopmental disorders. Among them are anxiety disorders (PTSD, phobia and panic), autism, schizophrenia, Williams syndrome and fragile X (Schuman, et al. 2011; LeDoux, 2007). Though, this does not mean that the amygdala is causing these disorders, rather that the amygdala is altered in patients with these disorders.

Accordingly, each of these disorders includes the feeling of fear and anxiety, which might explain why the amygdala is involved. However, more research is required before conclusions can be drawn on that matter.

To conclude

There are several factors in the field that has to be taken with caution in order to improve further developments and findings in the future (Zald, 2002; Phelps & Anderson, 1997). For instance there is the difficulty in integrating conflicting findings achieved through different approaches. It is clear that different measuring methods and paradigms yields different conclusions regarding how the amygdala is functioning. Because the current measuring methods such as EEG, MEG, fMRI and PET has sensitivity differences to spatial, temporal and other aspects of amygdala registration during task performances. The variety of paradigms and measuring methods demonstrates complex and different results, which ends with difficulties in drawing strong united conclusions when comparing the results. Furthermore, the distinction between when the amygdala is activated and to what task performances amygdala activation is required has to be clarified. In addition, further research into the interactions between the amygdala and other brain regions would end in better understanding of the amygdala generally. Altogether, these obstacles being solved would provide with a better picture of the human and animal amygdala when processing and responding to sensory stimuli.

In conclusion, the amygdala is now more conceptualized as a fear structure, since it plays a key role in fear related situations. During which the amygdala is critical in order for humans and animals to be able to learn and respond to fear related stimuli, where, damage to the amygdala impairs the concept of fear in both humans and animals. Further amygdaloid damage also impairs the ability to detect danger and predict previously learned

information related to danger. Thus the amygdala is a key component that informs and warns humans and animals through its parallel pathways when danger is encountered. That much is well established about the amygdala. Finding solutions to above mentioned obstacles will improve the understandings of the amygdala in general and of its functional properties. Future studies with brain scanning machines such as fMRI and PET and lesion studies in patients, might address the role of the amygdala in emotional recognition, emotional expression, and how emotions are experienced. Additionally these improvements will also aid the efficiency of investigating the current hypothesis about the amygdala, that its function is more complex and goes beyond the one stated above about emotions. Where, it is suggested that the amygdala is involved in determining what a stimuli is and what the organism should do in turn.

References

Adolphs, R. (2008). Fear, faces and the human amygdala. *Current Opinion in Neurobiology, 18,* 166-172. DOI 10.1016/j.conb.2008.06.006

Adolphs, R., Tranel, D., Damasio, H. & Damasio, A. R. (1995). Fear and the human amygdala. *The Journal of Neuroscience, 15* (9), 5879-5891.

Aggleton, J., P. (2000). The amygdala. A functional analysis. Oxford University press.

Anderson, A. K., Christoff, K., Panitz, D., Rosa, E. D., & Gabrieli, J. D. E. (2003). Neural correlates of the automatic processing of threat facial signals. *The Journal of Neuroscience, 23*(13), 5627-5633.

Cahill, L., & McGaugh, J. L. (1996). Modulation of memory storage. *Current biology, 6,* 237-242. doi:10.1016/j.neuropsychologia.2006.04.021

Cahill. L., Haier. R. J., Fallons. J., Alkire. M. T., Tang, C., & Keator, D. (1996). Amygdala activity at encoding correlated with long- term, free recall of emotional information. *Neurobiology, 93,* 8016-8021.

Cahill, L., Uncapher, M., Kilpatrick, L., Alkire, M. T., & Turner, J. (2004). Sex-related hemispheric lateralization of amygdala function in emotionally influenced memory: an fMRI study. *Learning & Memory, 11*, 261-266.

Dellacherie, D., Hasboun, D., Baulac, M., Belin, P., & Samson, S. (2011). Impaired recognition of fear in voices and reduced anxiety after unilateral temporal lobe resection. *Neuropsychologia*, *49*, 618-629. doi:10.1016/j.neuropsychologia.2010.11.008

Jimenez, S.A., & Maren, S. (2009). Nuclear disconnection within the amygdala reveals a

direct pathway to fear. *Learning & Memory, 16,* 766-768.

Kensinger, E. A., Addis, D. R., & Atapattu, R. K. (2011). Amygdala activity at encoding corresponds with memory vividness and with memory for select episodic details. *Neuropsychologia, 49,* 663-673. dio.10.1016/j.neuropsychologia.2011.01.017

LaBar, K. S., Gatenby, J. C., Gore, J. C., LeDoux, J. E., & Phelps, E. A. (1998). Human amygdala activation during conditioned fear acquisition and extinction: a mixed-trial fMRI study. *Neuron, 20,* 937-945.

LaBar, K. S., LeDoux, J. E., Spencer, D. D., & Phelps, E. A. (1995). Impaired fear conditioning following unilateral temporal lobotomy in humans. *The Journal of Neuroscience, 15* (10), 6846-6855.

LeDoux, J. E. (1994). The amygdala: contribution to fear and stress. *Seminars in the Neurosciences, 6*, 231-237.

LeDoux, J. E. (1996). The Emotional Brain. New York: Simon & Schuster.

LeDoux, J. E. (1998). Fear and the brain: where have we been, and where are we going? *Society of Biological Psychology, 44*, 1229-1238.

LeDoux, J. E. (2000). Emotion circuits in the brain. *Annual Review of Neuroscience, 23*, 155-184.

LeDoux, J. E. (2007). The amygdala. *Current Biology, 17,* (20), R868-874.

LeDoux, J. E., Cicchetti, P., Xagoraris, A., & Romanski, L. M. (1990). The lateral amygdaloid nucleus: sensory interface of the amygdala in fear conditioning. *The Journal of Neuroscience, 10*(4), 1062-1069.

Liddell, B. J., Brown, K. J., Kemp, A. H., Barton, M. J., Das, P., Peduto, A., Gordon, E., Williams, L. M. (2005). A direct brainstem-amygdala-cortical-'alarm' system for subliminal signals of fear. *NeuroImage, (24*), 235-241. doi:10.1016/j.neuroimage.2004.08016

McGaugh, J. L., Cahill, L., Roozendaal, B. (1996). Involvement of the amygdala in memory storage: Interaction with other brain systems. *Proc. Natl. acad. Sci., 93,* 1350-13514.

Öman, A. (2005). The role of the amygdala in human fear: Automatic detection of fear. *Psychoneuroendocrinology, 30,* 953-958. doi:10.1016/j.psyneuen.2005.03.019

Pessoa, L. (2011). Reprint of: Emotion and cognition and the amygdala: From "What is it?" to "What´s to be done?" *Neuropsychologia, 49,* 681-694. doi.10.1016/j.neuropsychologia.2011.02.030

Phelps, E. A., & Anderson, A. K. (1997). Emotional memory: What does the amygdala do? *Current Biology, 7,* R311-R314.

Phelps, E. A., LeDoux, J. E. (2005). Contribution of the amygdala to emotion processing: from animal models to human behavior. *Neuron, 48,* 175-187

Rosen, J. B., & Donley, M. P. (2006). Animal studies of amygdala function in fear and uncertainty: Relevance to human research. *Biological Psychology, 73,* 49-60. doi:10.1016/j.biopsycho.2006.01.007

Schafe, G. E., Nader, K., Blair, H. T., & LeDoux, J. E. (2001). Memory consolidation of pavlovian fear conditioning: a cellular and molecular perspective. *Trends in Neuroscience, 24* (9), 541-546.

Sigurdsson, T., Doyere, V., Cain, C. K., & LeDoux, J. E. (2007). Long-term potentiation the amygdala. A cellular mechanism of fear learning and memory. *Neuropharmacology, 52*, 215-227.

Schumann, C. M., Bauman, M. D., & Amaral, D. G. (2011). Abnormal structure or function of the amygdala is a common component of neurodevelopmental disorders. *Neuropsychologia, 49,*745-759. doi.10.1016/j.neuropsychologia.2010.09.028

Wager, D. T., Luan Phan, K., Liberzon, I., Taylor, S., F. (2003). Valence, gender, and lateralization of functional brain anatomy in emotion: a meta-analysis of findings from neuroimaging. *NeuroImage, 19,* 513-531. doi.10.1016/S1053-8119(03)00078-8

Whalen, P. J., Rauch, S. L., Etcoff, N. L., McInerney, S. C., Lee, M. B., & Jenike, M. A. (1998). Masked presentation of emotional facial expressions modulate amygdala activity without explicit knowledge. *The Journal of Neuroscience. 18* (*1*), 411-418

Zald, D. H. (2003). The human amygdala and the emotional evaluation of sensory stimuli. *Brain Research Reviews, 41*, 88-123.