Human Emotional Memory: Physiological, Pharmacological and Neuropsychological Investigations.

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That, with the exception of the administration of the California Verbal Learning Test to patients SE & DR in chapter six, and the administration of the slide story assessment to patients SE & DR also in chapter six, it is the record of work carried out by me.

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I dedicate this thesis to my parents,
Chris and Jude Papps
and to my sisters,
Emma and Nicola.

For their support and love.

ABSTRACT

Human emotional memory: physiological, pharmacological and neuropsychological investigations.

This thesis addressed the nature of arousal and its impact on human memory by assessing the degree to which response characteristics, stimulus characteristics, pharmacological and neurological characteristics affect memory for emotional material. Understanding the mechanisms by which emotions affect memory may contribute to attempts to ameliorate clinical disorders, which are characterized by intrusive traumatic memories.

In experimental Chapter 2, frequency-matched words rated as highly arousing were remembered consistently better than low arousal rated words with a normal pattern of decay over a series of 4 recall intervals occurring over one week in a within-subject design. Galvanic skin responses to the same words that were high or low at the time of stimulus presentation did not predict memory at these intervals. Chapter 3 assessed the role of the central noradrenergic (NA) system in memory for emotional material. Pharmacological processes believed to occur at the time of arousal and which are believed to be involved in the encoding of specifically emotional memories were manipulated. It was predicted that NA re-uptake inhibition would result in an increase in memory for the emotional compared to neutral material. The study demonstrated a dose-dependent effect opposite to the predicted direction. The fourth experimental chapter studied the effects of physiological response characteristics alone on memory. Memory was assessed in subjects who demonstrated low physiological reactivity to images (high 'alexithymics') compared to controls (low 'alexithymics') but who did not demonstrate differences in subjective emotional responses. While differences in physiological reactivity existed between high and low alexithymics, no differences in memory were observed. In Chapter 5, free-recall memory for images combined with incongruent sounds was better than free-recall memory for images that were combined with congruent sounds. Presentations that were rated as unpleasant (low valence) and highly arousing were remembered better than other categories regardless of stimulus incongruity. Chapter 6 investigated hemispheric differences in emotional memory functioning in man. A patient with right amygdala damage showed evidence of an emotional but not neutral memory impairment over four tasks compared to age and education matched healthy controls. By contrast, another patient with damage to the left amygdala performed similarly to the controls on the same tasks. These findings, taken together indicate a) subjective rather than physiological responses to stimuli predict memory performance in healthy adults. b) the *interaction* of low valence (pleasantness) ratings and high arousal ratings is associated with superior recall in healthy adults. c) the effects of emotion on memory are not due to other stimulus characteristics such as distinctiveness d) that increasing the level of the neurotransmitter noradrenaline (modulated by emotional arousal) does not improve emotional memory and e) the right amygdala in humans may be more critical for emotional memory functioning than the left amygdala in humans.

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Publications resulting from this thesis

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Papps, B. P., & O'Carroll, R.E. Emotional memory: consolidation, incubation or decay? Neuropsychologia. (submitted).

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Ben Papps, July 2001.
Institute of Psychiatry.

OVERVIEW OF THE EXPERIMENTAL CHAPTERS OF THIS THESIS

CHAPTER TWO

Previous research indicates that the memory trace for material that elicits an arousal response (GSR) may grow or become stronger over time. This 'incubation effect' translates into poorer memory for 'emotionally arousing' material as compared to neutral material when assessed immediately after presentation, but better memory for emotional material than neutral material when assessed after a delay interval. However, present research does not differentiate between subjective, self-rated 'arousal' and physiological arousal in response to stimuli in studies of human memory. In addition, to-be-remembered stimuli are not matched for frequency of occurrence in the English language. The study reported in this chapter investigated human word memory performance over 4 time periods following presentation (immediate recall, 30 minute recall, 24 hour recall and 7 day recall) employing a within subject design. Words presented for later recall were classified as emotional or neutral and matched for frequency of occurrence in the English language. 'Emotional' and 'neutral' words were defined in three ways. (A) Arbitrarily defined as 'taboo' or 'neutral'. (B) According to whether subjects produced above or below threshold verbal ratings of how emotionally aroused they felt when presented with words. Alternatively, (C) according to whether a subject produced an above or below threshold change in galvanic skin response from baseline at the time of word presentation. When words were matched for frequency

of occurrence and defined arbitrarily as either taboo or neutral, taboo words were better remembered than neutral words and memory decayed over time. Words were also matched for frequency of occurrence and defined according to whether subjects produced above or below threshold verbal ratings of how emotionally aroused they felt when words were presented. Above threshold words were consistently more likely to be recalled than neutral words with a pattern of decay occurring for both classes between the 24- hour memory test and the seven-day memory test, again there was no evidence of an incubation effect. Finally, words were defined according to whether a subject produced an above or below threshold change in galvanic skin response from baseline at the time of word presentation. There was no significant difference between recall of above and below GSR threshold words over the 4 recall intervals. Furthermore, the expected pattern of decay occurred for all words such that more words were recalled at tests occurring within 24 hours of the presentation compared to the test occurring after seven days. Taken together, no evidence of incubation was found using three separate methods of classifying words as emotional or neutral.

CHAPTER THREE

Animal literature and a growing body of human evidence implicate the central noradrenergic system in the process of memory modulation for emotional material. Blockade of the beta-adrenergic system in humans results in decreased recall and recognition memory performance, relative to placebo, for elements of a series of slides accompanied by an emotional narrative. Stimulation of this system with yohimbine has resulted in increased recall and recognition performance relative to placebo for the same stimulus materials.

The study reported here manipulated the central noradrenergic system using 4mg and 8mg doses of a new selective noradrenaline re-uptake inhibitor, reboxetine, in a double blind, randomized between group, placebo controlled design. It was hypothesized that noradrenergic re-uptake inhibition would result in a dose dependent increase in free recall and recognition memory performance, relative to placebo, for the emotionally arousing material.

The study found a dose dependent effect on recall and recognition scores *opposite* to the predicted direction (placebo> 4mg>8mg reboxetine) and no significant differences between groups in self-rated stress and arousal scores or self-rated emotional reactions to the stimuli.

CHAPTER FOUR

Intense emotional events lead to an increase in physiological arousal and such events tend to be well remembered. If physiological responses predict memory performance, then reliable differences in memory should be evident between subjects who demonstrate differences in physiological 'reactivity' to 'to-be-remembered' stimuli. One such group that has been reported as demonstrating decreased physiological reactivity compared to healthy people has been labeled 'alexithymic'. Alexithymia is a term used to describe a 'cognitive affective style' in healthy people characterized by an inability to describe feelings. This chapter reported the results of a study comparing the physiological variables of blood pressure and heart rate during baseline relaxation periods and in response to a series of emotional and neutral slide stimuli in subjects producing extreme scores on a questionnaire measuring the construct of alexithymia. High alexithymics and low alexithymics produced equivalent self-ratings of emotional arousal in response to a series of slides depicting

an emotional story. They differed on one physiological measure recorded in the laboratory. High alexithymics produced lower levels of physiological reactivity as expressed by the change in heart rate from relaxation versus emotional slide presentation compared to low alexithymics. However, there were no significant differences between the groups when memory for the stimuli was assessed at a surprise memory assessment following a seven-day delay.

CHAPTER FIVE

Research on the psychology of emotional memory requires a consideration of the effects of the 'unusualness' of an emotional stimulus on memory. It is possible that emotional stimuli are more unusual than neutral stimuli and it is, perhaps, this unusualness rather than the emotional nature of the stimulus that predicts memory. Psychological studies of memory for emotional events have directly studied the effects of emotion and unusualness on memory. Christianson and Loftus (1991) tested subjects' memory for depicted images in slides. In the 'emotional' condition, subjects' memory was tested for central and peripheral details of a road-traffic-accident scene depicting a woman lying critically injured in the middle of a road by her bicycle. In the neutral version, the woman was depicted riding her bicycle in the road and in the 'unusual' condition, the same woman was depicted walking in the middle of the road carrying her bicycle on her shoulder. Memory for the central detail of the emotional scene (colour of the woman's top) was better than memory for the peripheral detail (colour of a parked car in the distance). In the unusual condition subjects performed poorly on both the central and peripheral detail. This study indicates that the effects of emotion on memory are different from the effects of 'unusualness' on memory.

Previous research indicates that structures in the brain involved in the regulation of the human autonomic nervous system response to threat respond to stimuli that are unusual or distinctive. These same structures may have a time-limited role in memory formation for the stimuli that initiate an emotional response. The between-subject design study reported in chapter three tested long term recognition and recall memory for visual and auditory stimuli that were combined either (a) congruently or (b) incongruently. In addition, these 'congruent' or 'incongruent' stimuli had been categorized as (1) low valence high arousal, (2) low valence low arousal, (3) neutral, (4) high valence low arousal or (5) high valence high arousal. Subjects who had been presented with incongruent combinations of sounds and images recalled significantly more images at a one- week 'surprise' free recall test than subjects who had been presented with congruent sounds and images. In addition, most images were recalled from the low valence, high arousal category (i.e. rated as the least pleasant and most arousing) regardless of the congruity or incongruity of the stimulus. This study also demonstrated significant differences between categories and groups in terms of subjective self-ratings of how pleasant (valence) and how arousing subjects found depicted images. This was not mirrored by significant between group differences in physiological responses such as GSR and heart rate in response to the presentations. Therefore differences in memory performance were evident in the absence of differences in physiological responses but in the presence of differences in subjective valence and arousal self-ratings.

CHAPTER SIX

Single case studies of humans with amygdala damage have demonstrated an apparent impairment in these subjects' recognition memory performance for emotional but not neutral material. The metabolic activation of the healthy right

amygdala has been shown to be correlated with the recall of emotional but not neutral material. This study investigated the possible effects of differentially severe amygdala damage in the left or the right hemisphere on emotional memory performance. The study included a patient with bi lateral amygdala damage more severe in the left hemisphere than the right (DR), and a patient whose damage was more severe in the right than in the left hemisphere (SE). Both these patients' performance on a series of four tasks was compared to the performance of healthy age, IQ, education and neutral memory matched controls. Results indicated that, in the first instance, right amygdala damage is associated with a failure to show the heightened recognition memory scores for the middle, negatively valenced, emotive phase of a slide story presentation (compared to first and third phases). Left amygdala damage was associated with normal performance in this task. In the second instance, right amygdala damage was associated with a selective impairment in memory for negatively valenced emotional words compared to neutral words. Left amygdala damage was associated with normal performance in these tasks. In the third instance right amygdala damage was associated with a tendency to take longer to respond correctly to low valence high arousal images, low valence low arousal images and high valence high arousal images versus healthy controls. Left amygdala damage was associated with normal performance on this task. The increase in recognition time associated with right amygdala damage relative to left hemisphere damage was reversed in response to neutral images. In the fourth instance, right amygdala damage was associated with impaired overall picture recall performance relative to controls, left hemisphere damage resulted in normal performance on this task. In addition, right amygdala damage was associated with a failure to recall any images that had been briefly presented to the right hemisphere.

Chapter One

General Introduction

"Selection is the very keel on which our mental ship is built. And in the case of memory its utility is obvious. If we remembered everything, we should on most occasions be as ill off as if we remembered nothing" (William James, 1890)

1.1 Introduction

It is clear that not all memories are remembered equally well, and that this selectivity in memory has important consequences in terms of human and animal survival. Emotionally arousing experiences tend to be well remembered, sometimes, *too* well remembered. Nowhere is this more evident than in the well-documented physical and psychological consequences of severe trauma. In the diagnosis of Post-Traumatic Stress Disorder for example, the clinician would expect to see evidence of specifically emotional intrusive memories rather than neutral intrusive memories. It seems important to understand what psychological and biological processes occur by which some memories, in certain conditions, in certain people might become intrusive and debilitating. Understanding how the biological aspects of emotion

interact with human memory might help us reduce the distress caused by intrusive emotional memories while leaving neutral memory relatively unaffected. The beneficial implications of this kind of therapeutic modulation of memory are clear.

The study of memory for emotional material provides an important interface between fields of study that have, for many years, been mutually exclusive to a certain degree. Biological approaches to the study of emotion and retention have often disregarded cognitive aspects of human memory. Psychological studies of human memory, growing especially from the behaviourist tradition, have largely progressed without a consideration of the role played by emotion or biology. It is suggested here that the neurobiological literature relating to animal learning and memory should inform research directions in human memory studies of arousal and memory.

Memory performance in humans is complex and difficult to study. At an intuitive level, it would appear that to have an emotional reaction to something should ensure that the source of the emotional reaction, the elicitor of the response, should be better remembered than if the source did not illicit an emotional reaction. To take an everyday example, one might predict that the colour of an articulated truck that had veered towards a driver's car in morning rush-hour traffic would be better remembered by the driver of the car than the colour of that same truck had it passed the car uneventfully. However, it is difficult to claim with confidence that a person's memory for an arousal producing stimulus would be in some way improved

compared to memory in a neutral scenario, indeed there is evidence to indicate that, in some circumstances, the opposite may be true (Christianson, 1992).

1.1.1. Aims of this Chapter

This chapter will review evidence from neurobiology and psychology that relates to animal and human 'memory' for emotional material. To review the history of research on emotion in biology on the one hand, and memory per se in psychology on the other would clearly be beyond the scope of this thesis.

The initial section of this review deals with animal and then human evidence to support the hypothesis that emotional arousal modulates (enhances or impairs) memory performance. This section will concentrate on neurobiological evidence for the role of certain hormones and neurotransmitters in the animal and human body produced during and following arousal-eliciting events in memory modulation.

This neurobiological evidence will be extended to consider the role of certain brain *structures* in memory modulation for emotional events. This research moves from a neurobiological perspective to a neuropsychological perspective when evidence is reviewed for the role of certain brain structures in *human* emotional memory functioning.

The second part of this review assesses the human psychological literature on memory for emotional material. This literature contains the main contradiction that although emotional arousal modulates memory (enhances/impairs), the direction of this modulation is often unclear. This section will then review the degree to which this lack of clarity may be due to a) a more complex interaction between the effects

of emotion on memory than previously thought, or b) the range of methodological approaches employed across studies, or c) The distinction between subjective and physiological arousal.

1.1.2 The term 'emotional memory' as used in this thesis:

There is a degree of divergence in the current literature concerning the most appropriate definitions to employ in the studies of memory for emotional material. The divergence in opinion is partly due to the range of ways human memory can be studied. Joseph LeDoux and others have extensively studied processes of classical conditioning of fear responses in animals and in humans. The term 'emotional memory' is used by LeDoux (1996) to refer mainly to the processes by which a physiological arousal response can be learned in the absence of a declarative or episodic memory. An example of an early case of what LeDoux calls 'emotional memory' is the classic neurological case study of a female anterograde amnesic (Clarapede, 1911). In the complete absence of any signs of recognition of him from the patient, or memory for their recent conversations on successive meetings, Clarapede, on one occasion, concealed a pin in his hand and shook the patient's hand, pricking her in the process; the patient recoiled as expected. The next time he returned to meet the patient, there was, as usual, no sign of recognition of him on her part, but she refused the usual offer of a handshake. She could not describe the reasons behind her unwillingness to shake hands. It seemed to Clarapede that the patient remembered something of their previous meeting. The memory system represented by the behavioural avoidance observed in Clarapede's case study has

been described as an example of implicit or non-declarative memory for dangerous or otherwise threatening stimuli. Some researchers describe it as 'emotional memory' in the sense that it is a reflexive physiological response and does not require explicit memory for the circumstances under which the physiological memory was formed (LeDoux 1996). This is in contrast to declarative memories for emotionally arousing situations, which are clear explicit memories for facts and propositions that can be recalled and communicated. Memory for an experience can be explicit in nature and with or without associated physiological arousal, but for the explicit memory to have a physiological component requires the activation of an "emotional memory system". The present thesis reports a series of studies of declarative memory of emotionally arousing stimuli. Some research reviews suggest that enough evidence exists to indicate that the implicit and explicit/declarative nature of memory may be dissociable. For example, it is possible that there may be separable memory systems underlying conscious and non-conscious emotional memory functioning. However, for this to be the case, studies would have to demonstrate the existence of declarative memories for emotional events in the absence of physiological concomitants *and* be able to demonstrate participants forming implicit 'memories' in the absence of declarative or explicit memories (Christianson 1992). Some evidence does exist that suggests that, in amnesia, implicit or emotional memory may occur in the absence of explicit memory (Clarapede, 1911; Christianson & Nilsson 1989; Johnson et al., 1985). However, evidence to support the reverse position (i.e. explicit memory for emotional

experience in the absence of physiological change) is less robust (Greenberg et al., 1984).

It appears that human memory for emotional material 'behaves' in a number of different ways. On a non-conscious level, a stimulus-response relationship can be built via the processes of classical conditioning of fear responses. In such circumstances a conditioned stimulus can elicit a change in physiological arousal levels. However, except in cases of amnesia (e.g. Clarapede's case) this 'physiological memory' seldom occurs in the absence of an explicit or declarative memory of emotion outside the laboratory in healthy humans. It is suggested here that using the term 'emotional memory' to describe conditioned arousal may be misleading because it gives the impression that the study of emotion and memory can only be confined to classical conditioning. As outlined later in this thesis, the term 'emotion' in human memory studies can be defined in a number of ways; in terms of elicited physiological arousal or in terms of self-rated subjective responses to stimuli. It is possible to argue that, for declarative memory, or conscious recollection, a subjective emotional response (i.e. a self-rating of arousal) might be more predictive of later memory performance than a physiological index of arousal.

It does not appear that the study of the brain structures underlying memory for emotional material in humans can be confined to studies of classically conditioned physiological responses. Structures in the brain believed to be involved in fear conditioning may also mediate the 'storage' of declarative memory for emotional events in other brain systems involved in memory, this modulation may occur in a time-limited way (Cahill & McGaugh, 1998). By this account, structures

involved in classical conditioning of emotional responses may *also* influence more long- term declarative memories but only when those memories are emotional in nature. Accordingly, these structures are not involved in overall memory functioning but are selectively involved in emotional memory functioning (*both* declarative and non-declarative).

The experimental chapters of this thesis involved attempts to assess both the physiological changes that occur when 'emotional' stimuli are presented to human participants and also the subjective, self-rated responses that occur when these stimuli are presented. Recall and recognition memory was assessed in these studies for the stimuli presented and not classically conditioned responses. By studying declarative memory for emotional stimuli alongside both physiological and subjective reactions to those stimuli allow conclusions to be drawn relating to the ways in which stimuli, responses and declarative memories interact. Therefore, this thesis uses terms such as 'memory for emotional material' and 'emotional memory' to refer to the declarative, conscious, or explicit nature of memory unless otherwise stated.

1.2. Biological aspects of memory for emotional material.

1.2.1 The links between emotion and the storage of memory.

Many published psychological studies of memory for emotional material end with a speculative comment about possible biological or neurological systems or mechanisms that may underlie observed human behaviour. Taken together, studies

of memory for emotional events either in the laboratory or in the field have often produced a degree of variability in results. A number of experimental constraints present themselves when measuring memory in humans for events occurring outside the laboratory, especially. For example, the claim has been made that negative or traumatic real life events are remembered particularly well (Brown and Kulik, 1977; Reisberg et al., 1988; Yuille and Cutshall 1989). There is often a concordance, within-participants, in their memory for traumatic real life events (Christianson, 1989, 1992; Brown and Kulik, 1977). Event information tends to be well remembered in such circumstances, as does circumstantial information (the informant, location, time, other activities engaged in, when the news was heard etc.) leading to the suggestion that, due to the arousing nature of the event, all accompanying information is 'captured' and processed allowing detailed recall. The use of the term 'flashbulb' memory (Brown and Kulik, 1977) develops the analogy of the memory 'snapshot' in such situations, where all events occurring at or around the time of the traumatic event are captured and remembered as if photographed and printed.

It is clear that in some circumstances memory for traumatic events can be remembered more readily and, at times more accurately than events that are not traumatic, given the same delay between event and memory assessment, but there are numerous problems in interpretation of these results. Memories for highly emotional events are by no means internally accurate; confabulation is often a hallmark of testimony. There is often a wide range of variables other than the independent variable itself that affect the dependent variable. There is often no

adequate baseline event against which to compare memory performance for the traumatic event. Even with an adequate baseline, it is often impossible to determine the degree to which memory for the traumatic event (and not the neutral event) is aided (or harmed) by subsequent media coverage, social intercourse or internal 'rumination' and rehearsal. Theories of flash bulb memory formation raise questions about the reliability or veracity of self reported memories of traumatic events. The Easterbrook hypothesis states that arousal 'narrows' the focus of attention and improves memory for the central rather than peripheral elements of a to-be remembered stimulus (Easterbrook, 1959). This hypothesis has stimulated research over the past 40 years into phenomena such as 'weapons focus' effects in the memory performance of witnesses of serious or violent crime.

1.2.2 Weapons Focus.

The weapons focus effect describes the observation that witnesses of violent crime selectively focus on a particular element of the scene at the expense of other elements of the scene. The weapons focus effect can be used as an example of the Easterbrook claim (1959) that emotion narrows the focus of attention. The effect describes an often-observed pattern in eyewitness memory for traumatic events. "The weapon appears to capture a good deal of the victim's attention, resulting in, among other things, a reduced ability to recall other details from the environment, to recall details about the assailant, and to recognise the assailant at a later time" Loftus (1979) p. 35. This would appear to be an extreme manifestation of the Easterbrook hypothesis where the definition of what is central and what are peripheral shifts to

extremes. It has been suggested in previous studies that the immediate protagonists in an emotional event can be considered part of the central detail of that event. However, in the weapons focus phenomenon it would appear that the most critical central detail is the weapon itself and all other detail; even the details associated with the assailant are classified as peripheral. It is not unreasonable to suggest that the weapons focus phenomenon represents the 'endpoint' of the Easterbrook hypothesis. If we evolve to avoid threat etc it makes sense that attention should be devoted to the aspects of events that represent most *immediate* threat. The gun in the weapons focus effect represents such a threat.

It should be noted however that weapons focus findings are not always replicable. Kuehn (1974), in an analysis of police reports indicated that robbery victims gave fuller descriptions of assailants than rape/assault victims. If arousal is associated with increased recall accuracy relating to the weapon at the expense of the perpetrator, we should expect robbery victims to give a relatively poor description of the assailant.

Many studies claim to either support or refute the Easterbrook hypothesis. Many of the studies are difficult to compare and therefore interpret because of the wide variety of to-be-remembered materials, methods and definitions concerning what is central and what is peripheral in memory scenarios. A further problem with many of these studies is one that stimulates a consideration of the biological aspects of emotional memory. Studies often fail to identify the aspects of an event that may occur alongside arousal but which may play an equal or a more important role in the formation of memories for that event. It is conceivable, for example, that

exciting, emotional or arousing events serve to increase the levels of attention to, or rehearsal of those events. What is described as emotional memory in the psychological literature, declarative memory for emotional events, may be a reflection of some other process that occurs alongside emotional arousal (like attention or rehearsal) which does not, in itself require emotion to modulate memory.

It seems therefore that to claim that arousal at learning influences subsequent memory strength does not necessarily mean that it is arousal per se that does the influencing. In order to make such a claim with confidence requires the demonstration that emotional arousal affects physiological processes involved in learning, i.e. that there is some direct causal link between emotion and the encoding and storage of memories (via underlying brain processes).

This is not to claim that attention and rehearsal should be treated as epiphenomena in the study of emotion. The degree to which an event captures the attention, the degree to which it arouses, and the degree to which events are 'thought about' at a later time are all critical aspects in the process of everyday memory for emotional events. However, to isolate the processes by which emotions influence memory storage in the laboratory requires either the exclusion or experimental control over variables other than emotion.

1.2.3. Historical context: Psychological data and biological processes

Donald Hebb was among the first to bridge the divide between the psychological and biological aspects of memory. In Hebb's memory span studies, a series of nine digits were read aloud to college students, a memory assessment for

the digits followed each nine-digit presentation and few tended to recall nine when assessed with consecutive novel strings. Over the course of 24 trials, with every third set of digit strings repeating the first set, participants gradually learned the repeating series while performing poorly on novel items. Hebb (1972) explained these effects in terms of short and long-term memory. He proposed that short-term memory could be understood in terms of active, limited duration processes, while long-term memory might require some form of structural change in the nervous system. He proposed that synapses could be functionally connected in what he called 'cell assemblies'. Central to his conception of cell assemblies was the notion of functional links between any two neurones excited together.

"When an axon of cell A is near enough to excite a cell B and repeatedly or persistently takes part in firing it, some growth process or metabolic change takes place in one or both cells such that A's efficiency, as one of the cells firing B is increased" (Hebb 1949)

The idea that "cells that fire together wire together" led to the proposition that short-term memory was the 'reverberation' of the cell assembly following initial sensory input. Repeated reverberations could produce structural change via (in Hebb's view) the growth or functional increase of synaptic connections. This lasting structural change in synaptic connections might explain the phenomena of long-term memory for the digit spans in his human experimental studies. More recently, a review of the field (Goddard et al., 1980) suggested that, in keeping with

Hebb's assertion, there are separate neural substrates for short term/primary and long-term/secondary memory. "Electrical stimulation of a neurone can produce brief or long lasting changes in synaptic transmission"(Bliss & Gardner-Medwin, 1973). The response magnitude of neurones has been found to increase immediately after high frequency stimulation (posttetanic potentiation). It either gradually returns to baseline or remains elevated (long-term potentiation). The similarity between posttetanic potentiation and long-term potentiation respectively and short- and long-term memory have been emphasised by Goddard (1980).

Although there appears to be tentative evidence in support of Hebb's theory, there are a number of ways in which 'real world' memory mechanisms may be more complicated. In the first instance, it appears that long-term potentiation depends upon posttetanic potentiation; in other words, the formation of long-term memory requires a functional short-term memory. This is the implication of both physiological studies of posttetanic potentiation and early psychological models of memory functioning (Atkinson & Shiffrin, 1968). Early psychological models treated memory functioning in a modal way and indicated that, in order for the flow of information to reach a 'long-term store' it needed first to pass through the 'bottleneck' of the short-term memory system. However, single cases of neuropsychological impairment appear, at least on the surface, to question that position. A strong argument exists in the neuropsychological literature to indicate that long-term memory systems and short-term memory systems may be separable and, to a certain degree, mutually exclusive. This claim is based on double dissociation of long-term and short-term memory processes found in amnesia.

Patients suffering from amnesic syndromes have been found to demonstrate normal short-term memory performance in the face of grossly impaired long-term memory (Milner 1966; Baddeley & Warrington 1970). The reverse can also occur (Shallice & Warrington, 1970) where immediate memory span can be impaired while long-term learning appears normal). The explanation of memory in terms of 'reverberating circuits' falls short of accounting for the differential effects of lesions to different brain locations on short- and long-term memory. A second way in which 'real world' memory mechanisms may be more complicated involves the impact of arousal on memory functioning. There appear to be processes that operate in different ways depending on the affective nature of the to-be-remembered stimulus. For example, Livingstone (1967) and later Brown and Kulik (1977) were among the first to suggest that systems may exist whereby *all* recently activated brain events are stored in memory. The implications of so called 'flashbulb memory' theories are that certain memories will be 'printed' (Brown & Kulik, 1977) regardless of the number of times that they are repeated or rehearsed.

1.2.4 Psychopharmacological evidence for 'emotional memory' in animals

Extensive evidence exists in the animal literature to suggest that certain underlying brain processes modulate memory in response to specifically emotional reactions. McGaugh (1993) has argued that emotional responses to experiences indicate that those experiences are important to remember. This intuitive

observation leads to the assumption that the significance of an event should correlate positively with memory performance (McGaugh, 1990).

Experimental research with animals indicates that electrical stimulation (McGaugh, 1966) and certain drugs (McGaugh & Herz, 1972) administered post-training can affect memory storage. While post-training electrical stimulation has been found to cause retrograde amnesia in some studies (McGaugh, 1966), it has been found to enhance retention when applied to some brain regions (Bloch, 1970). Emotionally activated hormonal systems have been demonstrably linked with the regulation of memory storage (de-Wied, 1984; McGaugh, 1983; Morley & Flood, 1991). Adrenaline (epinephrine) is released from the adrenal medula both during and immediately after stressful stimulation in mice and rats. When rats are trained in a passive inhibitory avoidance task, post-training injections of adrenaline tend to be associated with dose and time dependant enhanced retention (Gold & van Buskirk, 1975). Retention is found to be enhanced with low doses and impaired at high doses. The enhancement of retention was greatest in the Gold and van Buskirk study when injections of adrenaline were administered shortly after training. This effect has been demonstrated across a number of tasks and at delays of up to one month (Introini-Collison & McGaugh, 1986) providing strong support for the memory-modulating role of endogenously released adrenaline.

It is clear, however, that a number of different substances are involved in modulating memory storage. Neurotransmitters and hormones such as acetylcholine, adrenaline, noradrenaline, vasopressin, GABA and the opioids all have been implicated in this process. Studies of experimentally induced stress in animals

imply a role for opioid peptidergic and GABAergic systems in the modulation of memory storage. Treatments that affect these systems seem to involve the activation of noradrenergic receptors in the amygdala (Castellano et al 1990; McGaugh 1989). Injecting opiate antagonists into the amygdala (naloxone/naltrexone) appears to enhance retention (Gallagher & Kapp, 1978; Introini-Collison et al, 1989; Messing et al 1979). An additive effect on memory enhancement has also been demonstrated when naloxone and epinephrine are injected in low doses after training (Introini-Collison & McGaugh 1987). The stria terminalis is a major amygdala afferent-efferent pathway; lesioning the stria terminalis blocks the effects of naloxone (McGaugh et al, 1986). Taken together, this evidence indicates a) that opiates may impair retention, b) that adrenergic hormones and opiates may work together via a common mechanism and c) that a dedicated neural architecture that is critical for emotional memory may include the amygdala and the stria terminalis. It also seems that both opiate antagonists' and epinephrine's' common effect may be the influences these substances have on the release of noradrenaline (NA) in the brain.

1.2.5. The involvement of the amygdala in opioid, hormonal, GABAergic and noradrenergic influences on memory storage.

Experiments employing both systemic (i.e. distributed throughout the organism) and intra-amygdala (within the amygdala) injections of NA, as well as opiate agonists and antagonists indicate a role for the amygdala in mediating

memory storage. Retention is found to be enhanced by opiate antagonists and impaired by opiate agonists (Gallagher, 1982; 1985; Gallagher & Kapp 1978). Also, the effects of naloxone on memory performance are blocked in animals with lesions to the dorsal noradrenergic pathway (see Fanelli et al 1985; Gallagher et al 1985). Post-training intra-amygdala injections of B-adrenergic antagonists block the effects on memory of systemically administered naloxone (McGaugh et al, 1988). These two findings suggest that in the first instance, the effects of opioid peptides seem to be mediated by influences involving noradrenaline. In the second instance, the naloxone effect involves noradrenaline within the amygdala, rather than surrounding areas.

Retention seems to be modulated by GABAergic drugs also, and again, their effects seem to involve noradrenaline within the amygdala. Picrotoxin (a GABAergic antagonist) was found to enhance maze learning in rats when administered after training (Breen & McGaugh, 1961). This effect has been demonstrated across a range of tasks (Bovet et al, 1966; Brioni & McGaugh, 1988). GABAergic antagonists (pictrotoxin and bicuculine) and GABAergic agonists (muscimol and baclofen) have been found to enhance and impair retention respectively (Brioni & McGaugh et al., 1988; Castellano et al 1989; Swartzwelder et al, 1987). GABAergic antagonists and opiate antagonists are additive in enhancing memory (Castellano et al 1989) once again indicating a common mechanism. As with opiate agonists and antagonists reported earlier, bicuculine (a GABA antagonist) injected post-training into the amygdala, produces dose dependant enhancements in retention (Brioni et al, 1989) while baclofen and muscimol impair

memory (Castellano, et al, 1989). This suggests that opiate agonists and antagonists produce similar effects on memory as GABA agonists and antagonists. Lesions to the amygdala block the effects of GABAergic drugs also, as indicated by the failure of bicuculine (GABAergic antagonist) and muscimol (GABAergic agonist) to affect retention in mice with amygdala lesions (Ammassari–Teule et al, 1991). GABAergic memory influences may, like opioid peptidergic influences, involve the activation of NA receptors also. This is indicated by studies that show that systemic or intra amygdala administrations of the B-adrenergic antagonist propranalol block the memory enhancing effects of GABA antagonists.

It seems that central NA receptors are involved when epinephrine modulates memory by activating the amygdala. Intra- amygdala injections of propranalol (B-adrenergic antagonist) block the memory enhancing effects of systemically administered epinephrine (Liang et al 1986). More directly, retention (of inhibitory avoidance tasks) is found to be enhanced by posttraining amygdala injections of NA (Intrioni-Collison et al., 1991; Liang et al., 1986; Liang et al., 1990). Furthermore, these effects are blocked by lesions to the stria terminalis (the major afferent efferent pathway from the amygdala). The picture emerging from the research with animals has been summarised in a model of the interactions of hormones and neurotransmitter systems in regulating memory storage for emotional events (see Figure 1.1 below and McGaugh 1993 for this model).

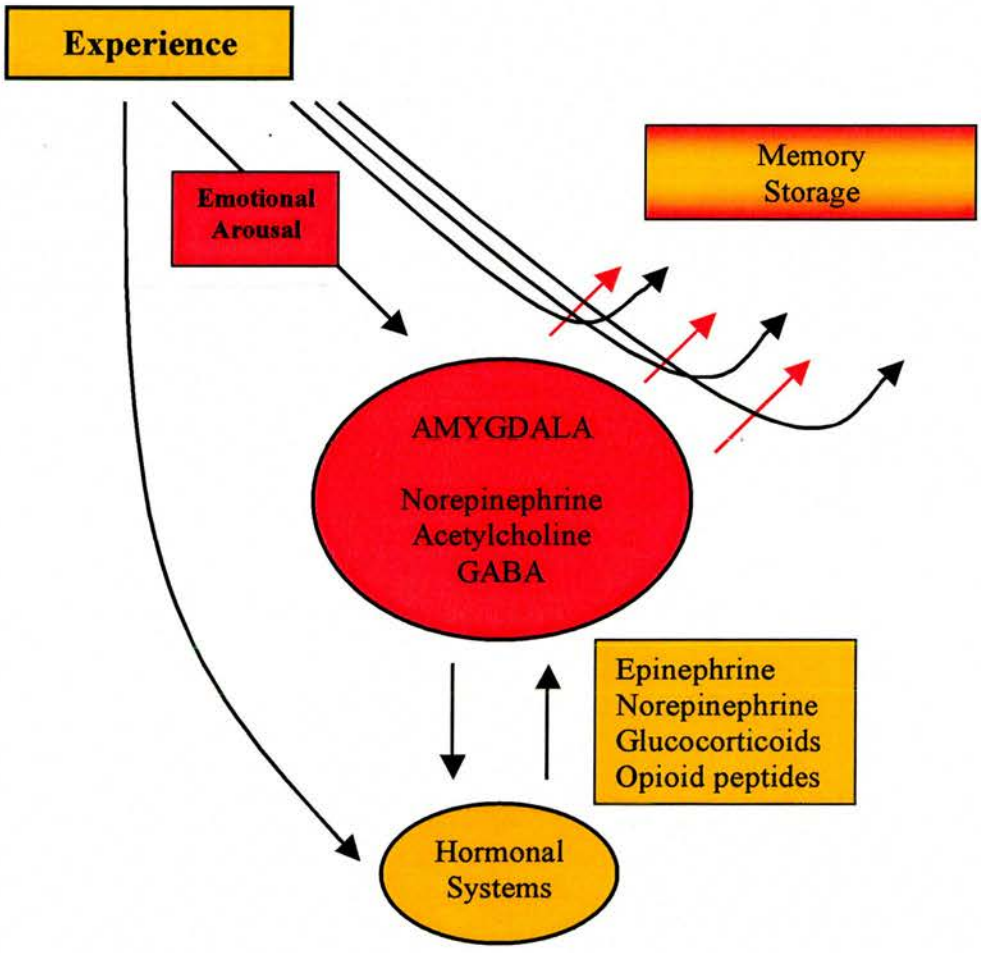


Figure. 1.1. A schematic representation of how hormonal systems and the amygdala complex can modulate the storage of memory for emotionally arousing events through influences on other brain systems. (adapted from McGaugh 1993).

The model suggests that following an emotional stimulus, the body releases stress hormones such as adrenaline (from the adrenal medulla), which activate a central noradrenergic system that projects to the amygdala. The amygdala is activated and influences the storage of the specifically emotional memories in brain

regions involved in memory. According to such models the amygdala, activated by a central noradrenergic system, has a time-limited role in the storage of arousal-mediated memory.

1.2.6. Noradrenergic activity and the modulation of human memory

Studies of human explicit memory for emotional material during pharmacological manipulations are needed to fully determine the degree to which the animal findings apply to human memory. The neurobiological mechanisms involved in human memory for emotional material remain relatively poorly understood. In an influential study, Cahill (Cahill et al., 1994) reported that blocking the adrenergic system in humans using the β-adrenergic blocker propranolol resulted in impaired memory for an emotional 11-slide story presentation. The slide show presentation concerns a boy who leaves home with his mother to visit his father. On their way, the boy is involved in a serious car accident and is rushed to a nearby hospital where his severed legs are surgically reattached. Participants viewing the slide series do so under what are essentially false pretences. They are told that the slide presentation is used to study arousal. They are not told that the real focus of the study is memory until they return 7 days later, when they perform free-recall and multiple choice recognition memory tests for the slides presented. Normal healthy controls show a peak in memory performance for the middle phase of the story when the emotional components are introduced (Cahill et al., 1994; Cahill et al., 1995; van Stegeren et al., 1998;

O'Carroll et al., 1999a; O'Carroll et al., 1999b). This phase includes a graphic slide of the boy's reattached feet on an operating table. In the original Cahill et al (1994) study, half of the original propranolol treated participants viewed a closely matched story accompanied with a non-emotional narrative, and these participants (unlike the propranolol participants who viewed the slides with the emotional version of the narrative) did not show impaired memory. This memory modulation could not be attributed to effects on attention, sedative effects or emotional reactions because there was no difference in terms of subjective ratings when the propranolol and placebo participants were compared. It therefore appeared that blocking the adrenergic system had a direct effect on subsequent memory in humans for emotional but not neutral material.

The mechanism by which propranolol may exert its effects on memory remains unclear. Propranolol crosses the blood-brain barrier freely and acts both inside and outside the central nervous system. The memory effects found by Cahill and colleagues (1994) may have been due to the effects of either or both the central or peripheral action of the drug. Subsequent attempts to determine the degree to which the memory impairing effect of beta-blockade are mediated by central or peripheral mechanisms have produced inconsistent results. O'Carroll and colleagues (1999a) found no differential effects of either central or peripheral beta-blockade relative to placebo on memory for the 11-slide story presentation. All three groups showed the normative heightened recall for the central emotive phase of the presentation. Other researchers (van Stegeren et al., 1998) using a similar methodology found that participants receiving propranolol (which crosses the blood-

brain barrier) showed an impairment in memory for the middle, emotionally arousing phase of the story, whereas participants receiving nadolol (a beta-blocker that does not cross the blood-brain barrier) did not differ significantly from placebo, i.e. they displayed the normative enhanced recall for the middle phase. This led these researchers to claim that "memory of a mild emotional event involves activation of central, but not necessarily peripheral beta-adrenergic receptors."(van Stegeren, 1998 p305). Since this finding, further evidence has implicated the noradrenergic system in emotional memory (O'Carroll, 1999b). Using the same slide-stimulus set with participants randomly allocated to beta-blockade (using metoprolol) or noradrenergic stimulation (yohimbine), O'Carroll et al., (1999b) demonstrated that yohimbine enhanced and metoprolol impaired both free-recall and recognition memory for the emotional version of the 11 slide story, relative to placebo. Although the studies outlined above have implicated the noradrenergic system in human memory for emotional material, it is important to note that the effects of yohimbine are not specific to the noradrenergic system; dopamine and 5-HT are also affected following yohimbine administration (Den Boer et al., 1993). The hypothesis that the noradrenergic system is intimately involved in the encoding of memories for emotional material is specifically addressed in Chapter 3, where human memory for both emotional and neutral material is assessed following noradrenaline re-uptake inhibition.

1.2.7. *The amygdala and memory for emotional material*

1.2.7.1 Animal evidence: permanent versus time-limited theories of amygdala involvement in memory.

The amygdala has been implicated as a structure intimately involved in the formation and storage of fear responses in the mammalian brain (Le Doux 1996; 1998). It has also been suggested that the structure may modulate memory for specifically emotional material in a more time-limited way in the mammalian (Packard et al., 1994) and human brain (Cahill et al., 1995; 1996). The structure has received extensive research attention in recent years (see Aggleton, 2000). Research with animals has mapped out the circuitry involved in fear conditioning (LeDoux, 1998). This pathway begins with transmission of sensory stimuli about the conditioned stimulus (a tone previously paired with a shock for example) to the amygdala via thalamus and cortex. It culminates in the control of autonomic nervous system arousal responses by outputs of the amygdala (heart rate, blood pressure changes for example). Lateral / basolateral (L/BL) amygdala lesions in animals impair the expression of conditioned fear. (see Figure 1.2 for a schematic representation of the nuclei of the amygdala). Conditioned fear in animals is usually measured by the startle response to a tone in the presence of a cue previously paired

with a foot shock (known as a fear potentiated startle - Le Doux, 1995; Maren and Fanselow, 1996; Davis 1997). L/BL lesions made one month following conditioning trials have been found to impair FPS (Lee et al., 1996; Maren et al., 1996). This suggests that lesions such as these block the acquired startle and that the lesioned nuclei may be the site of storage of conditioned fear "...attaching 'fear' to the previously neutral stimulus and remembering it is what the amygdala does" (Stevens 1998).

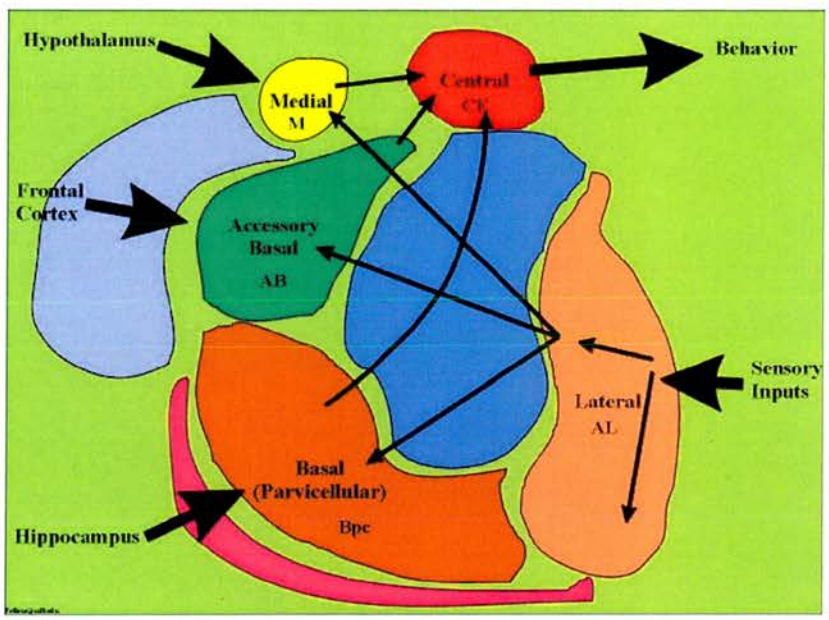


Figure 1.2 Schematic representation of the nuclei of the amygdala. The information pathway seems to consist in a common entry point (the lateral nucleus), several parallel streams to other nuclei (Medial, accessory basal, or basal, for example) and a common output point (the central nucleus) with its connections to the central nervous system. Each of the internal streams is modulated by other brain structures such as the hippocampus, the frontal cortex or the hypothalamus. (Pitkanen et al 1997).

However, other researchers have argued that an important distinction should be made in lesion studies before claims about the amygdala and fear conditioning can be drawn with any confidence. This distinction is called the Learning /

Performance Distinction. Cahill and colleagues (1999) have argued that it is critical to distinguish a lesion's effect on memory from a lesion's effect on other areas of performance. It is important that a lesion should disrupt a conditioned response and not an unconditioned response before the lesioned area can be implicated in conditioning. For example, it is possible that a lesion to nuclei of the amygdala may effect 'freezing' behaviour per se and not conditioned freezing behaviour in particular. According to Cahill et al (1999), there are no demonstrations in which lateral basolateral nuclei of the amygdala impair conditioned freezing or FPS while unconditioned freezing or FPS remains intact.

It has also been suggested that the amygdala may play a more time-limited role in memory formation for emotional events. For example, Packard and colleagues (1994) found that stimulation of the amygdala influenced storage of specific kinds of memory thought to involve specific brain areas. Amphetamine was micro-infused into the amygdala, hippocampus or caudate nucleus of rats immediately following a training period on one of two water-maze tasks. One task was a spatial task, the other, a visually cued task. Infusing amphetamine into the hippocampus selectively enhanced retention of the spatial task and infusing amphetamine into the caudate nucleus selectively enhanced retention of the visually cued task. However, the amygdala infusions enhanced retention of both tasks. If the amygdala was inactivated with lidocaine immediately before the retention tests, enhanced memory was still observed. Packard and colleagues' reasoning here was that if nuclei of the amygdala enhance or impair memory in a particular structure, stimulation of the

amygdala should influence formation of the type of memory thought to involve that structure in a time-limited way.

1.2.7.2. Single cell recording in the amygdala: implications for studies of human emotional memory functioning.

The evidence indicates that the amygdala may be involved in a range of emotional memory processes in animals and humans. Specifically the amygdala has been implicated in a) fear conditioning (e.g. LeDoux, 1996), and b) the modulation of declarative memory for emotional events (e.g. Cahill, 2000; McGaugh et al., 2000). The literature on auditory classical conditioning of fear has a number of implications for the study of human memory for emotional events. Lesion studies have pinpointed the sites involved in learning about an auditory stimulus; learning that it is associated with aversive shock. Le Doux et al (1985) have demonstrated that lesions to the auditory midbrain and auditory thalamus disrupt fear conditioning whereas lesions to the auditory cortex do not disrupt fear conditioning. This finding indicated that the information relating to the aversive stimulus did not have to reach the level of cortex for conditioning to occur. Some area of the brain other than the auditory cortex might receive this output. Although primary nerve fibres carry signals from the auditory thalamus to the auditory cortex, cells in some regions of

the auditory thalamus also give rise to fibres that connect to sub-cortical areas like the amygdala. Lesioning the amygdala alone among these sub-cortical structures disrupted auditory fear conditioning (Le Doux et al, 1985). It appears therefore that in classical conditioning paradigms, a sound can determine the emotional significance of a stimulus (a shock) in terms of memory functioning and that the higher order functions of areas like the cortex (implicated in conscious recollection in humans) is not necessary for this type of learning. However, the emotional significance of an aversive event is not only determined by a sound (or other conditioned stimulus) but by the *circumstances* in which the conditioned stimulus occurs. So, for example, an animal such as a rat must learn that a sensory 'cue', be it auditory or visual, is dangerous in certain environmental situations. To take a human example, the sight of a coiled poisonous snake, inches away, but behind glass in a zoo should not signal imminent danger, however the sight of the same snake inches away in the open should prompt relatively more earnest avoidance. This basic premise, that conditions play a role in conditioned reactions to and memory for certain stimuli, has important implications for memory.

Experiments have demonstrated that structures in the brain involved in declarative and spatial memory formation are separable from those involved in conditioned arousal responses. Kim and colleagues (1992) and Phillips & LeDoux (1995) demonstrated that lesions to the amygdala interfere with an animal's conditioned response to the tone presented and to the environment in which the tone is presented (i.e. the chamber). However, lesioning the hippocampus disrupts responses to the chamber only (not the tone). This is consistent with the notion that

the hippocampus plays a role in processing complex stimuli (including spatial information). Projections from the subiculum of the hippocampus to the amygdala also indicate that contextual or spatial information may acquire emotional significance under certain circumstances.

However, it is difficult to determine under what circumstances contextual or spatial information may acquire emotional significance. It is clear that the circumstances might differ between individuals, but it seems reasonable to suggest that mechanisms may exist which determine the degree to which a given context will elicit arousal. One of the ways in which the effects of environment upon conditioning can be assessed is to study the ways in which cells respond in the amygdala to information from the environment. The ways in which these cells respond, their response parameters, may indicate the conditions under which conditioned responses may occur.

Long-term potentiation has been implicated in memory formation (Kelso & Brown, 1986). In long-term potentiation, when the neurotransmitter glutamate binds with NMDA receptors, calcium ions precipitate strengthened neural transmission. The establishment of LTP allows the same neural signals to produce larger responses in future. NMDA receptors have been found in the amygdala suggesting that this form of memory may occur in this structure. Single cell recording in the amygdala has been studied by Bordi and colleagues (1992; 1994) while rats are listening to a tone and receiving a shock. It has been demonstrated that every cell responding to auditory stimuli in the lateral nucleus of amygdala also responds to shock (Romanski et al., 1993). This finding suggests that the components and mechanisms of classical

conditioning of fear responses may occur in the lateral nucleus (AL) of the amygdala. When studying acoustically stimulated cells, Bordi & LeDoux (1992) found two classes of cells, those that were consistently responsive and those that were habituating. The existence of cells that habituate to sound in the lateral nucleus; i.e. cells that eventually stop responding when a sound is repeatedly presented, suggests that these cells may serve to support mechanisms that respond to sounds that are distinctive or unexpected. These habituating cells made up approximately 60% of the cells examined in the AL (Bordi & LeDoux, 1992). The consistently responsive cells in the lateral nucleus were found to have high intensity thresholds (above 10kHz). In itself, this would suggest that these cells can only be activated by loud sounds (interesting due to the role played by 'loudness' in judging distance and threat in the environment).

Evidence indicates that cells exist in the lateral nucleus of the amygdala that may play a role in detecting unusual sounds. The notion that associative long-term potentiation occurs in the lateral nucleus and that information about the tone and the shock in classical conditioning converge in these cells suggests that sound and shock pairing at these cells might serve to reduce habituation (by the action of the Hebbian rule perhaps). Such a reduction would allow the cells to respond to, rather than ignore significant, unexpected stimuli. The earlier observation that environmental conditions play an important part in the expression of classically conditioned responses is underpinned by observations at the cellular level. For example, the auditory stimulus of a 'hiss' from a poisonous snake could, arguably be classified as distinctive while walking in woodland and perhaps be seen as less distinctive if

heard in the context of a reptile house at a zoo. Equally, a loud 'hiss' in an unexpected or incongruent context such as a woodland context for example, may well signal the closeness and therefore the relative threat of attack. In such circumstances, the congruence of the stimulus with the surrounding context might determine the likelihood of danger. Incongruence may provide an important cue at a cellular level and at a behavioural level to signal an arousal response. It would also appear necessary for such 'threatening incongruence', having elicited arousal, to be well remembered. The role of stimulus incongruence, arousal (physiological and subjective) and memory functioning is assessed in Chapter 5.

The idea of stimulus 'congruence' interacting with the pleasantness/valence of a stimuli in predicting memory performance appears to be a testable hypothesis with human participants. Previous studies of the effects of manipulations of the 'usualness' and the emotional nature of images on memory performance have yielded interesting results. Christianson and Loftus (1991) presented healthy adults in different conditions with either emotional images, neutral or unusual images and tested subsequent memory for one central and one peripheral detail in each of the images. The neutral condition included an image of a woman riding her bicycle in the middle of a busy road. The emotional condition included an image of a woman lying injured in the middle of the road by her bicycle (the victim of a road-traffic-accident). The 'unusual condition' included an image of a woman walking in the middle of the busy road carrying the bicycle on her shoulder. The participants remembered more of the central than the peripheral details in the emotional picture but did not demonstrate this difference in the unusual condition. This suggests that

the processes influencing memory are different in memory for emotional compared to simply unusual material. In order to extend this finding, it is necessary to demonstrate that memory for identical pairs of stimuli can be modulated by manipulating 'unusualness'. The effects on memory of stimulus arousal, valence and congruence will be investigated in Chapter 5.

1.2.7.3 Single neuropsychological case studies following amygdala damage

Further evidence for the importance of the human amygdala in long-term recall for emotional arousing material in man comes from studies of the memory performance of patients with damage confined to this area (Babinsky et al., 1994; Markowitsch et al., 1994; Cahill et al., 1995; Phelps et al., 1998). (See Figure 1.3 for position of human amygdala in an MRI scan).

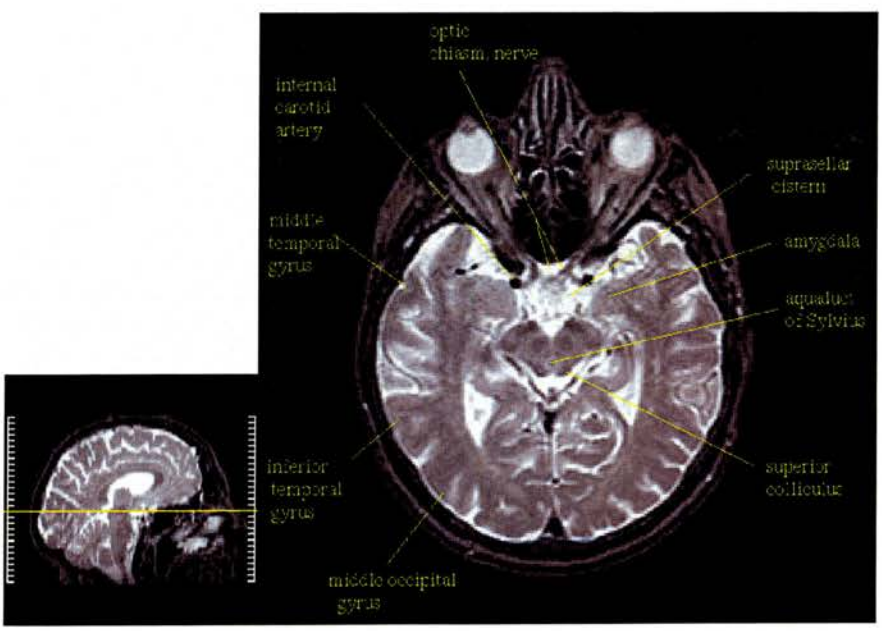


Figure 1.3. MRI scans showing the position of the human amygdala (T2 weighted slice 23)

The patient B.P. (Cahill et al., 1995) suffers from Urbach-Wiethe disease, a rare hereditary disorder that has produced selective and bilateral damage to the amygdala. He produced scores on attentional measures, intelligence measures and short- term memory measures in the normal range. This patient was presented with a brief narrated slide show depicting a story in which a mother and son leave their home to visit the boy's father (as described in section 1.2.6. and Appendix 2). On the way to visit the father the boy is involved in a horrific car accident while trying to cross the road, which results in emergency surgery on his severed feet at the local hospital. The emotional elements of this story are introduced in the second phase of the slide presentation (e.g. the accident, and surgery). Following the presentation of the story, the patient B.P. was required to rate the story in a similar way to the control participants in the study on a 0-10 scale. He was asked to rate the story in terms of how emotionally arousing he had found it. B.P.'s emotional reaction to the story was similar to that of the controls and yet, when memory was assessed for the slide/narrative presentation in a "surprise" test after a seven day interval, pronounced differences in memory were evident between the patient and the controls. The controls showed enhanced memory for the second phase of the story (the emotional phase). The patient performed similarly to the controls on the first essentially neutral phase but failed to show the normative pattern of enhanced recall for the second, emotive story phase.

Controversy still exists relating to whether the human amygdala underlies fear conditioning per se or long-term emotionally influenced declarative memory in

man. Phelps et al., (1998) have extended the single case approach to investigations of emotional memory following amygdala damage to address this question. They assessed a 54 year- old female, SP who had bi-lateral damage, on a variety of cognitive tasks. The tasks included an examination of fear conditioning, memory for differently valenced words, memory for neutral words embedded in emotional sentences, word memory changes over time, and memory performance for the same slide story presented to the patient B.P. (Cahill et al., 1995). They found that the patient SP failed to produce the normative pattern of enhanced memory for the middle arousing phase of the slide story (like B.P.). S.P. also demonstrated deficits in tests of fear conditioning (however, it should be noted that other studies of amygdala damaged patients have not shown deficits in fear conditioning – Tranel & Damasio et al., 1993). With their episodic memory tasks, Phelps et al (1998) demonstrated that when memory benefited from the effects of arousal (rather than valence) in healthy controls, bilateral damage to the amygdala led to a deficit in performance. The study of these two dimensions (i.e. arousal and valence) is based on multivariate analysis in studies of affective language indicating that the principal variance in emotional meaning is explained by factors of pleasure (valence) and arousal (e.g. Smith & Ellsworth, 1985).

The evidence briefly reviewed above indicates an important role for the amygdala in enhanced episodic memory for material that is specifically emotional in man. The evidence also suggests that fear conditioning, a process disrupted after lesions of the amygdala nuclei in other animals, may also be disrupted in humans

following amygdala damage (although this is equivocal). The evidence accrued thus far relating to the *damaged* human amygdala indicates that bilateral damage is associated with impairment of emotional memory. However, studies of amygdala activation in healthy participants indicate that lateralised effects in activation of the structure may be predictive of emotional memory performance. The relationship between right hemisphere amygdala activation and episodic free-recall for emotional material indicates the possibility that the right amygdala rather than the left is in some way more critical in terms of long-term emotional memory performance (Cahill et al., 1996 – see section 1.2.7.4). Asymmetries in brain function have been observed in both animal and human imaging studies (Logan & Grafton, 1995; Nyberg et al., 1996; Tulving et al., 1994; Kapur et al., 1995; Squire et al., 1992). It has been suggested that encoding and retrieval may involve different hemispheres of the brain. For example, the right prefrontal cortex has been implicated in memory retrieval (Tulving et al 1994; Kapur et al., 1995) and stimulation of the left AC alone modulates memory storage in rats (Packard et al., 1994). In the animal literature, the right AC rather than the left appears to be implicated in memory retrieval. It is possible that single case studies demonstrating emotional memory impairment after bi-lateral amygdala damage conceal more subtle hemisphere effects on memory for emotional material. If the right amygdala in particular is involved in memory for emotional material, then a patient with right amygdala damage or bi-lateral damage should show an impairment in memory performance for the slide story presentation similar to the performance of B.P (Cahill et al, 1995). On the other hand, a patient with amygdala damage confined primarily to the left hemisphere should demonstrate

memory performance on the slide materials similar to normal healthy adults (i.e., the patient should demonstrate an increase in memory performance for the middle 'emotive' phase of the story.

1.2.7.4. Human studies of the healthy amygdala

Recent advances in functional neuroimaging techniques have permitted studies of amygdala function in humans that have attempted to demonstrate differences in metabolism in different brain structures during memory tasks in healthy adults.

Cahill and colleagues (1996) used positron emission tomography of cerebral glucose metabolism in healthy adults to investigate the relationship between amygdala activation and long-term memory for emotional material. In a within-participants design, participants were shown two videos during PET scanning. These sessions were separated by 3 – 7 days. The emotional video consisted of 12 emotionally arousing film clips while the neutral video consisted of 12 relatively neutral film clips. Three weeks following the second video session, free-recall memory performance in the participants was assessed over the telephone. Immediately following the presentation, participants produced higher emotional reactions to the emotional film clips as compared to the neutral clips, and participants recalled significantly more of the emotional film clips than the neutral film clips after a three-week interval. The metabolic activity of the right amygdaloid complex (AC) while the clips were being presented was significantly correlated with the number of emotional film clips recalled after the three-week interval. AC activity

was not correlated with the number of neutral film clips recalled at the three- week interval. These results were interpreted by the authors as providing evidence that the right AC is selectively involved with formation of enhanced long- term memory for emotional material in man. The study reported a relationship between right amygdala activation and long-term, episodic emotional memory performance. Similar findings have been reported by other researchers (Rauch et al., 1996). However, aversive classical conditioning paradigms during PET scanning have not demonstrated amygdala activity (Hugdahl et al., 1995). Thus far, it would appear that the human amygdala might play a more complex role in human emotional memory than simply forming and storing classically conditioned associations between aversive stimuli. However, it is clear that the formation of such associations on the one hand and long-term episodic memory for aversive material on the other need not be mutually exclusive functions of the amygdala. The study reported in Chapter 6 of this thesis tested the hypothesis that there is a clear relationship between right amygdala function and recall for emotional material in man. Emotional and neutral memory performance was tested in patients with amygdala damage in either the left or the right hemisphere.

1.3 Psychological studies of the effects of subjective arousal on memory

Studies of human memory for emotional events have produced equivocal results. Evidence indicates that negatively valenced emotional events are remembered differently from neutral or everyday events. However, some studies suggest that subjective arousal has a detrimental effect on memory (Clifford &

Hollin, 1981; Clifford & Scott, 1978; Loftus & Burns, 1982), other studies suggest that arousal has a beneficial effect (Brown & Kulik, 1977 Heuer & Reisburg, 1990; Reisberg et al., 1988 Yuille & Cutshall 1986, 1989)[1].

1.3.1. Arousal impairs memory: laboratory evidence of eyewitness memory.

In a survey of experts in eyewitness testimony (n=63) Kassin and colleagues (1989) found a strong consensus between experts about the negative impact of stress or violence associated with an event and subsequent memory performance. In response to the question "Very high levels of stress impair the accuracy of eye witness testimony" 71% of the experts suggested that the statement was reliable enough to offer in court. Deffenbacher (1983) reviewed 21 simulation studies of eyewitness memory. Ten studies reportedly demonstrated that high arousal led to increased eyewitness accuracy while 11 showed lower levels of accuracy. Most of the studies supported an inverted U-form relationship between arousal and memory [first described by Yerkes & Dodson (1908)]. Applied to human eyewitness memory, the inverted U-form relationship indicates that the highest levels of arousal during learning produce the poorest levels of memory performance at subsequent memory test. The U-form relationship between arousal and memory was developed by researchers in the early to mid eighties to encompass observation on the relationship between emotion and memory (Deffenbacher, 1983; Loftus, 1980). The

[1] A review of the vast psychoanalytic literature on repression and memory is beyond the scope of a thesis addressing the *experimental* evidence for the effects of emotion on memory. However, the interested reader is referred to a review of the degree to which psychoanalytic theories of repression are supported by experimental findings (Baddeley 1997 p273-277).

original inverted U-form curve relationship was developed by Yerkes and Dodson (1908) to describe arousal and performance in general (rather than arousal and memory in particular) and was proposed to account for data from animal learning studies. The relationship was such that extreme arousal corresponded with poorest levels of performance. Studies of human eyewitness memory differ, methodologically from animal studies of the effects of physiological arousal on performance, not least in terms of the degree of arousal elicited in each, and how arousal is measured. Human studies often involve the presentation of slides, videotapes, films or staged scenarios of either emotional or relatively neutral events, and memory is assessed either immediately following the simulation or following a delay. Typically memory is found to be poorer in 'emotional' simulations relative to neutral ones. For example Clifford and Scott (1978) found that performance on a 40-item questionnaire addressing details presented previously in either a 'violent' or 'non-violent' filmed scenario was worse in participants viewing the violent scenario. The films' content was equated in as far as the violent footage portrayed a violent assault on a bystander by a policeman and the neutral footage portrayed a verbal exchange between a bystander and a policeman. The items in the questionnaire covered the actions and physical descriptions of the protagonists. Although participants viewing the violent footage produced lower scores than participants viewing the non- violent footage, it is unclear as to whether the questions to participants relating to the bystander were the same in each group. In addition little information was presented concerning subject performance on different kinds of detail information relating to different aspects of the presentation.

This problem was addressed in a subsequent study (Clifford & Hollin, 1981) in which detail information in violent or non-violent filmed footage was varied. Participants' memories were assessed immediately after the presentation of either a film depicting a violent mugging or non-violent direction seeking. In each film, either three or five 'others' were portrayed in addition to the central protagonists [i.e. the central protagonists being the direction seeker (neutral version) or the victim of the mugging (violent version) and the principal other (either direction giver or the mugger)]. The description of the principal 'other' [i.e. the mugger (violent version) or direction giver (neutral version)] was more accurate following his portrayal in the non-violent film. The accuracy of recall in the violent condition decreased as the number of perpetrators increased. Interestingly, photographic identification (recognition) of the principal 'other' (perpetrator/direction giver) was not significantly different between conditions. Furthermore participants' memory of the woman (victim or direction seeker dependant on the film) indicated that accuracy was unaffected by violence (present or absent) or number of perpetrators (one, three or five). This study can be interpreted as providing some evidence to support the suggestion that depicted violence and perhaps the arousal elicited as result of that depicted violence influences subsequent memory in a complex way. It would appear that participants watching the violent filmed presentation were more susceptible to error as the number of perpetrators increased and yet memory for the victim remained unchanged. Participants' memory for the victim (who was a central protagonist) was unaffected by violence (present or absent) or perpetrator number. This suggests that memory for central details is robust in the face of faltering

memory for relatively peripheral details in violent scenes and remains robust regardless of the amount of to-be –remembered information in the scene. However, the study also raises questions about how 'central' information is to be defined. For example, it is difficult to gauge the 'centrality' of the different protagonists in the study. It would appear that memory for the victim remains unchanged while memory for the perpetrators does not remain unchanged.

Another frequently cited study of the effects of arousal on eyewitness memory indicates that certain types of detail information connected with a simulated emotional event are not necessarily remembered worse than similar details connected with a relatively neutral event. Loftus and Burns (1982) presented participants with either a violent or non-violent short video- taped scenario. In the violent scenario, a simulated bank robbery culminated in a scene in which a boy was shot by the perpetrators in the non-violent version, the bank robbery culminated with a relatively neutral scene of a conversation in the bank. Loftus and Burns compared memory performance between participants for a number of details associated with the robbery. They found that memory for a central element of the scene presented prior to the violent culmination was worse than memory for the scene presented prior to the non-violent culmination. The central element in the critical scene for which memory was assessed depicted the number on the boy's jumper. However, when memory was compared between participants on a number of other details associated with the robbery (time, actions of the bank teller etc) no significant differences were found between the groups. This study suggests the possibility that simulated violence may have a retrograde impairing effect on memory for detail,

however, it also suggests that not all detail associated with simulated violence is impaired.

The results of these studies would seem to imply that the relationship between emotion and memory in humans may be more complicated than the inverted U-form curve relationship between arousal and performance in animals. Not all 'emotional' information presented in human simulation studies is recalled poorly compared to neutral information. This may be because memory performance differs between studies as a function of the degree to which a stimulus elicits high or low levels of emotional arousal in participants. However, it is also possible that emotional arousal may exert its effects on memory in different ways (for example by affecting memory for central as opposed to peripheral aspects of the to-be –remembered stimulus). However, it is clear that such studies tend to be rather unclear with respect to the degree to which the scenes presented in studies of memory are 'emotionally arousing'.

An implication of such studies is that arbitrarily classified 'violent' material may detrimentally affect memory. However, the degree to which this finding can be used to support the hypothesis that emotional arousal detrimentally affects memory is questionable. Relatively little of the early work attempted to assess the degree to which participants themselves perceived the to-be-remembered stimuli as emotionally arousing or neutral. It is clear that human emotional reactions to stimuli presented in the laboratory are likely to be more complex to study that the emotional responses of animals. Nevertheless, any conclusion relating to emotional arousal and memory must measure emotional arousal responses in participants. It is suggested

here that both physiological reactions at the time of the presentation of to be remembered stimuli *and* self-rated emotional reactions to those same stimuli provide potentially reliable means of assessing the degree to which an emotional reaction to a stimulus predicts memory for that stimulus. In Chapter 2. of this thesis attempts are made to compare the memory performance of participants for stimuli classified in terms of self- rated reactions, arbitrarily classified and classified in terms of psychophysiological reaction and where possible this approach is utilised throughout this thesis. In Chapter 4., attempts are made to distinguish between the effects of subjective self –rated emotional reactions and physiological reactions to stimuli and subsequent memory performance. This is done in an attempt to directly test the effects of physiological arousal alone on memory performance. It is possible to argue that declarative memory formation in humans depends on conscious encoding of the to-be –remembered stimulus. Models of memory performance in humans based on animal research indicates that while classical conditioning may occur at the levels of sub-cortical structures, conscious cortical routes to memory storage may be modulated by sub-cortical structures involved in conditioned emotional responses (McGaugh, 1993, LeDoux, 1994). As outlined above, McGaugh and colleagues have developed models that suggest that structures in the human brain involved in classical conditioning of emotional responses may also have a time-limited role in human declarative memory. On this account, it would appear that declarative memory mechanisms, while dependant to a certain degree on the time-limited involvement of structures regulating the autonomic nervous system, may also depend on a conscious subjective emotional reaction. Such a self-rated emotional

reaction may therefore predict *declarative* memory for emotional material more reliably than physiological responses to that same material. In Chapter 4. of this thesis, the role of *physiological* arousal at encoding in predicting *declarative* memory is specifically tested in participants who demonstrate reliable differences in physiological responses to emotional stimuli compared to controls and not in self-rated emotional reactions. These participants are classified as 'alexithymic' (Sifneos, 1973). This term refers to normal healthy adults who demonstrate a 'cognitive affective style' characterised by an difficulty in naming feelings. These participants are often found to demonstrate similar self-ratings of emotional reactions to stimuli but reduced physiological responses (particularly heart rate reactivity in response to stimuli – Wehmer et al., 1995). It is suggested that, if subjective self-rated emotional arousal predicts declarative memories, then participants who are highly 'alexithymic' and demonstrate differences in physiological responses to emotional stimuli and not in subjective responses compared to normal controls, should not differ in their subsequent memory performance.

1.3.2 Arousal improves memory: Field evidence.

The evidence reviewed above relates to simulated laboratory studies of eyewitness memory. It has been suggested that the inverted U-form relationship between arousal and performance may not be adequate to account for human memory performance under conditions of extreme emotion. This is because, in the first instance, memory performance is not always poorer in 'violent' as compared to

non-violent scenarios in the laboratory. In the second instance, it is highly likely that the arousal elicited in animal studies of the effects of arousal on performance is both qualitatively and quantitatively different from the arousal elicited in human studies of eyewitness memory for violent or non-violent simulations.

Field studies of memory for real-life emotional events benefit from the fact that the attempts to elicit an emotional response are not simulated. However, they suffer because a number of methodological implications exist in studies occurring outside of the laboratory, not least of which are the effects of uncontrolled (and uncontrollable) variables, in addition to the independent variable (event-elicited emotion) on the dependant measure of interest (memory for that event).

There is a consensus between eyewitness testimony experts relating to the detrimental effects on memory for highly emotional real-life events (Kassin et al., 1989). It would also appear that a similar consensus exists between experts concerning the *beneficial* effects on memory of real-life negative or traumatic events. This appears to be somewhat contradictory in as far as eyewitness memory is often for real life events that are highly emotional. For example emotional memory for trauma has been described as "detailed, accurate and persistent" (Yuille and Cutshall, 1986). An analysis of eyewitness accounts of homicide collected soon after the crime by police and again 4 months later by researchers showed a high degree of consistency (Yuille & Cutshall, 1986). In addition, studies of autobiographical memory indicate that often, the more emotional the real life event, the greater confidence is expressed by those who have experienced it in terms of their own memory performance (Reisberg et al., 1988). In a study of the memory performance

of survivors of the Nazi concentration camp "Camp Erika", Wagenaar and Groeneweg (1990) found a consistently detailed memory performance over two time periods. The first time-period was 1943-1947, the second was 1984-1987. When testimonies were compared between time periods for the 78 study participants a high degree of consistency was observed. It appears that a hallmark of memory studies for real-life traumatic events is the consistency and detail with which events are remembered. However, it is not impossible for a memory to be consistent, detailed and inaccurate. For example, in another interview study carried out by Christianson and Loftus (1990) participants were asked to recall their 'most traumatic' memories. The researchers found a significant relationship between the rated degree of emotion and the number of 'central' but not 'peripheral' details remembered. It is clear from this study, that when people are asked to remember past traumatic experiences, some things are more likely to be remembered than others and it is important not to draw the conclusion that vivid memory for all aspects of the traumatic experience will be accurate.

1.3.2.1 Persistence and clarity in memory for emotional experiences: The 'flashbulb' effect.

Perhaps the best-known body of evidence to support the notion that highly emotional events are remembered clearly, correctly and persistently is evidence relating to 'flashbulb memory' performance. Memory performance for national events that are considered emotional (assassinations, accidents) often appear to be

consistently well remembered (Bohannon, 1988; Brown and Kulik, 1977; Christianson 1989). In addition, people often tend to be willing to report a range of circumstances associated with the traumatic memory but seemingly unconnected with the actual event itself. For example, often the specific circumstances under which the news was heard appear to be particularly well preserved (e.g. an ongoing activity, the informant, the day, and the time). Brown and Kulik (1977) proposed a mechanism where by highly emotional experiences may initiate the 'capturing' and preservation of information in great detail. The example given by Brown & Kulik in their seminal paper describes the apparent clarity of free-recall for the events central to the assassination of John F. Kennedy. The analogy has been drawn between this kind of memory and a computer 'printout' such that mechanisms may be initiated by severe trauma, which ensure that the event and details occurring at the time of the event are processed. In effect, as a flashbulb 'illuminates' everything in a darkened room for the briefest moment, the emotion or arousal elicited by a traumatic event may ensure that all information is remembered, however seemingly trivial, to a greater extent than would occur as a result of a relatively neutral event.

Although it would appear that public events that are emotional in nature are remembered well over long periods of time compared to everyday events occurring at a similar time, such memories are not as accurate as flashbulb memory analogies would suggest (McCloskey et al., 1988; Conway, 1997). In addition, there are a number of methodological caveats that exist in real life studies of memory, which mean that it is impossible to draw the conclusion that the emotion in relation to a public event causes better memory for that event compared to a neutral event.

In the first instance, studies of real life memory performance are often without an adequate baseline, an everyday event that is salient or unusual, similar in the detail to be remembered as the emotional event. Secondly, it is often impossible to verify accounts in terms of accuracy. It may be possible to verify the details of what occurred, but the fact that an account of what occurs is at odds with what actually occurred may reflect differences in memory or differences in the initial perception of the event between witnesses. Thirdly, differences in memory observed that pertain to a public event are often confounded with the effects of reinstatement. For example, it is possible to claim that one reason for the clarity observed in memory for emotional real life events is that the event itself is continually reinstated as a result of internal factors (post stimulus elaboration on the part of the witness) and external factors (media coverage). This reinstatement does not occur to the same extent with neutral events, indeed, it does not occur to the same extent between participants (for example, some have better access to media coverage than others). Drawing conclusions in relation to human emotional memory functioning from 'real-life' studies is therefore fraught with methodological difficulties. Laboratory studies, on the other hand are limited because of the simulated nature of the 'arousing' stimulus materials and the fact that, for ethical reasons, stimuli should not be too emotionally arousing. However, from an experimental perspective, it would appear that variables in the laboratory are more amenable to identification and control than variables in real-world studies. The challenge for laboratory studies of human memory for emotional material is clear. It is necessary to objectively demonstrate that the arousal eliciting materials used in lab-based studies elicit either

or both (a) subjective or (b) physiological arousal. One can then test whether subjective or physiological reactions to stimuli predict memory in healthy controls. It is established that dissociations are evident in amnesic patients between declarative memory and non-declarative memory (Clarapede, 1911; Johnson et al., 1985; Christianson & Nilsson., 1989), but the evidence relating to healthy adults is less clear. This can be determined at the stimulus level by adopting stimuli that demonstrably elicit differences in terms of emotion (as suggested by normative studies). This can also be done at the level of response by measuring physiological variables in response to a given stimulus.

1.3.2.2. A note on rehearsal: Are emotional memories remembered because they are just 'reinstated' more than neutral memories?

One possible reason for the strength and persistence of declarative memories for emotional events is the possibility that they are reinstated (via rehearsal perhaps) more often than neutral memories. Cahill (2000) has recently discussed the issue of rehearsal in emotional memory. It has been suggested by some researchers that the emotional memory effect can be explained by increased rehearsal (Niesser et al., 1996). In the case of 'flashbulb' type memories, this criticism is even more pertinent, because public events tend to be reinstated on a regular basis particularly by the media. However, manipulations in the laboratory benefit from the limited use of deception. 'Surprise' memory tests occurring after an interval minimise the possibility of between- subject differences in active rehearsal of to-be-remembered

stimuli. This approach was adopted in all the studies reported in this thesis and debriefing included questions relating to the degree to which participants thought their memory might be tested. The majority of the participants participating in the current series of studies communicated that they had not expected their memory to be tested. The data collected from participants who indicated that they had expected a memory test was not included in analysis.

Nevertheless, it is still possible to claim that some form of rehearsal takes place (be it 'active' or 'passive') and between-subject differences in this rehearsal contributes to some extent to the memory differences reported in studies of emotional memory. A direct experimental test of the hypothesis that emotional memory is advantageously affected by rehearsal was carried out by Guy & Cahill, (1999). They manipulated narrative rehearsal (subject discussion) of emotional and neutral film clips and tested memory for the films approximately 1 week later in a surprise memory assessment. The results indicated that the emotional film clips were remembered significantly better than the neutral film clips. This finding held for participants who did not rehearse the clips at all and for participants who engaged in narrative rehearsal. This finding indicated that an emotional memory advantage was evident in the absence of rehearsal. In general, the finding, coupled with the limited use of deception in emotional memory studies, suggests that emotional memory effects cannot be explained adequately in terms of rehearsal alone.

1.3.2.3. Emotion, Retention Interval and Memory incubation

It has been claimed that memory for emotional events may change over time. Retention intervals that are longer tend to produce improved memory for detail (Heuer & Reisberg, 1990; Christianson, 1984). In contrast, studies demonstrating that emotion impairs memory for details employ shorter delays between presentation and memory test (Christianson & Loftus, 1991; Clifford & Hollin, 1981).

In a series of classical studies, Kleinsmith and Kaplan (1963, 1964) found that for short intervals, memory was poorer for numbers associated with emotional words compared to neutral words. However, after a one- week delay, the opposite pattern was observed, memory was better for numbers associated with emotional words compared to neutral words. This finding would appear to indicate that memory for emotional material is not stable over time, but rather "incubation" apparently occurs (i.e. the increase in memory for emotional material). This effect has been replicated (see Eysenck, 1977 for a review). The original authors only used participants showing an emotional reaction to the words. What seems important in any attempt to address the question of incubation in studies of emotional memory, is a proper consideration of the stimuli employed. Kleinsmith and Kaplan's original study used 9 relatively neutral words particularly relevant to their 1960's sample of students (e.g. dance, exam etc). No explicit attempt was made to control for frequency of occurrence of the words in written and spoken English or for word

type, be it noun or verb. It seems clear that improved memory for words that are taboo may be partially explained by the fact that there were less of these class of words in circulation. A more recent study of arousal mediated memory consolidation was carried out at Yale by LaBar and Phelps (1998). They tested unilateral temporal lobectomy patients using an adapted version of the Kleinsmith and Kaplan paradigm which included a list of 40 words, 20 neutral, 20 taboo. Participants were required to learn these lists and rate them verbally for arousal. Memory for the words was assessed immediately and again after an hour delay. LaBar & Phelps found that both patients and controls generated higher GSR responses to the arousing words at encoding, but the controls, unlike the patients, showed a significant increase in memory (free-recall) for the arousing words over time. They suggested, quite reasonably that the medial temporal lobe structures may be involved in memory consolidation as they seem to be in other species (Packard et al., 1994). However, before we can draw inferences about the role of the amygdala in strengthening hippocampal-dependant memory consolidation just after the arousing task, it is important to ensure that the experimental and control stimuli are matched on a number of dimensions. La Bar and Phelps, for example made a presumption that their neutral words occurred as often as their taboo words but do not seem to have verified this with measures of word frequency. Matched stimuli would ensure that both neutral and taboo words are identical in all respects save for their 'neutralness' and 'tabooness'. In addition, a word that is taboo cannot necessarily be classed as emotionally arousing in the same way that a non-taboo word can be classed as not emotionally arousing. It seems necessary to assess the degree to which a word

produces both a subjective self-rating of high arousal and a physiological representation of arousal before it can be classified as truly arousing.

1.3.3. Summary and predictions

This brief review has suggested that research in the field of human emotional memory functioning should base research questions on an understanding of both biological and psychological theories of how emotion affects memory. A number of caveats exist in the current biological and psychological literature. The questions arising from this review will form the basis of the proceeding experimental chapters of this thesis. As a result of the psychological literature review, it appears, in the first instance, that any attempt to gauge the degree to which 'emotion' affects memory for stimuli requires a consideration of the nature of emotional arousal in studies employing human participants. It is suggested that the effects of physiological arousal be studied alongside the effects of subjective self-rated arousal on memory to determine the degree to which these two characteristics of the human emotional response act together or in isolation to modulate and predict human memory performance.

Chapter 2 of this thesis tests the hypothesis that emotion and arousal leads to memory incubation. The incubation effect, which implies that memory for emotional material is not only consolidated but that it increases over time, has not been adequately tested in the human literature. The consolidation/incubation explanation

is fundamental to certain explanations in the psychological literature relating to emotion's effect on memory. For example, it is suggested that the reason behind the contradictory finding that emotion sometimes enhances memory and sometimes impairs memory is the effect of retention interval. It has been claimed that emotion impairs memory for material tested under short delay and improves memory for details when tested following longer delays (Heuer & Reisberg, 1992). It is argued here that the degree to which the material is 'emotional' must be assessed using both subjective and objective measures of arousal before any conclusion can be drawn about emotion's effect on memory. In addition, any effect of 'incubation' must be separated from idiosyncratic stimulus effects on memory performance. The predictions made in Chapter 2 are a) the incubation effect may disappear when experimental and control stimuli are more strictly matched and that b) the incubation effect, if robust, should depend on the to-be-remembered stimuli actually eliciting an arousal response.

The study reported in the third chapter of this thesis addresses an unanswered question that is evident in reviews of the neurobiological literature. The question relates to the effect of a specific neurotransmitter manipulation on emotional memory performance. This review has argued that arousal should be classified in terms of its physiological and subjective components. One way to directly test the role of endogenous physiological processes in memory modulation is to manipulate both hormones and neurotransmitters implicated in the physiological response to emotional provoking material. The study reported in this chapter manipulates the specific neurotransmitter noradrenaline *in vivo* during the presentation of to-be-

remembered stimuli, and assesses subsequent effects of this manipulation on declarative memory. The prediction made in this chapter is that selective noradrenergic re-uptake inhibition will increase memory for emotional material compared to placebo.

The fourth chapter of this thesis attempts to address the question of the human emotional response to stimuli in the laboratory. The psychological literature consistently fails to classify stimuli employed in memory studies in terms of the emotional response elicited. It has been argued in this review that self-rated, subjective emotional responses to stimuli at presentation may be more predictive of later *declarative* memory performance than physiological arousal responses to those same stimuli. Furthermore, the current literature does not allow us to determine the full impact of 'arousal' on memory because it largely fails to distinguish the physiological and subjective elements of human emotional arousal. The prediction made in the study reported in Chapter 4 is that two groups of participants who differ in terms of their physiological response (like in 'alexithymic' individuals) to stimuli will only differ in terms of their memory performance if they also differ in their self-rated emotional response to the stimuli.

Chapter 5 of this thesis tests the hypothesis (as suggested by biological studies of the cellular processes that occur during emotional learning), that certain stimulus characteristics may determine the degree to which a) a stimulus elicits an emotional response and b) a stimulus is remembered. This chapter reports the results of a study designed to test predictions made on the basis of animal studies in terms of human memory functioning. The inferences drawn from the animal studies

reviewed and especially studies of the neural basis of classically conditioned fear responses (LeDoux 1996) make two predictions. The first prediction is that incongruent or unexpected stimuli will be better remembered than congruent or expected stimuli. The second prediction, based on the view that it is crucial to dissect emotion into components of arousal and valence, is that incongruent unpleasant stimuli will be better remembered than congruent unpleasant stimuli.

The study reported in the final experimental chapter of this thesis is again based on outstanding questions evident in a review of the neurobiological literature. This literature implicates the human amygdala in processes of formation of declarative memories for emotional events. The sixth chapter addresses the role of the human amygdala in emotional memory performance and tests the hypothesis that damage to the right amygdala results in disproportionately severe emotional memory impairments relative to left amygdala damage. The predictions made in this study are that patients who have right amygdala damage will show evidence of emotional memory impairments. Patients with amygdala damage in the left hemisphere will show emotional memory performance similar to healthy controls. In contrast, no differences should be evident in either patient in terms of neutral memory performance compared with healthy controls.

Chapter Two

Arousal and Memory incubation: Subjective versus Physiological Determinants of Memory Performance over Time

2.1. Introduction

The previous chapter demonstrated the breadth of scientific research demonstrating the current state of knowledge concerning the affects of arousal on memory. However, relatively little is known about how emotional arousal affects memory performance over different periods of time. The previous chapter has established that under certain circumstances, emotional material is remembered better than neutral material. A surprising effect of emotion on memory performance occurs when participants are required to learn, using the paired associate learning method, items that vary in emotional value. Results of several studies seem to imply that items associated with neutral, 'everyday' words are initially remembered better than items associated with words that are considered inappropriate or taboo, when memory is tested immediately after presentation of the to-be remembered stimuli. However, this position reverses with time, such that items associated with taboo words are remembered better (see this 'cross over' effect in Figure 2.1. below).

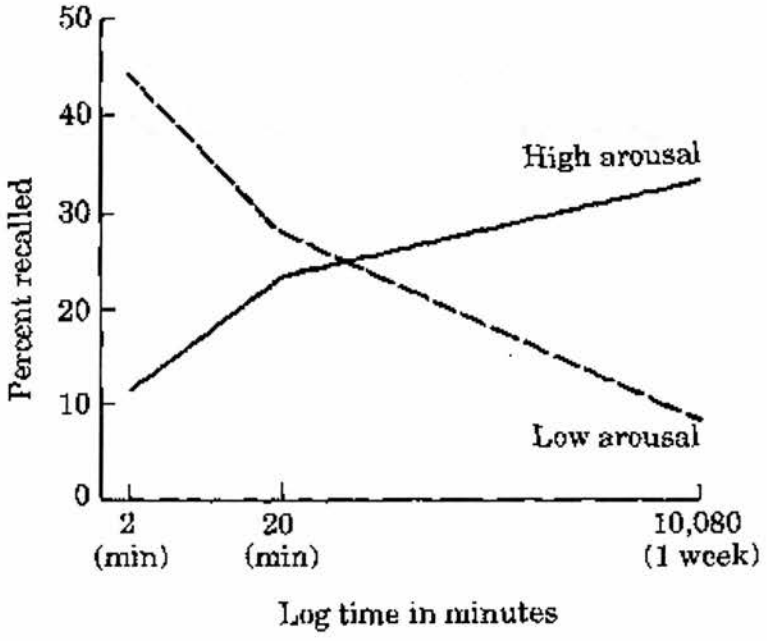


Figure 2.1 from Kleinsmith and Kaplan (1964) showing percent recall of high and low arousal items over time.

This pattern of memory performance suggests that processes of 'incubation' appear to occur during the encoding of emotionally arousing stimuli. Incubation is a process that occurs over time and is different from memory consolidation. Consolidation means that information is maintained (consolidated) in memory; incubation implies that memory for information may actually improve with the passage of time.

2.1.1. Incubation in human word list memory

The incubation effect was described in early studies of word-list memory. Perhaps best known are studies carried out by Kleinsmith and Kaplan (1963). Forty-

eight college students received a single learning trial in which word-digit paired-associate learning was employed and 9 word-number pairs were presented. Some words were selected to provoke a strongly emotional response in the sample of college students (e.g. rape, vomit) others less so (e.g. dance, swim). Participants were divided into 6 sub-groups (8 participants in each group), in a between-participants design. The six groups were tested one at each of the following recall intervals (immediate, 20 minutes, 45 minutes, 1 day and 1 week). Their results showed a sharp increase in per cent recall for arousing words over the first 45 minutes, with a less pronounced increase with a one- day and one- week interval. In comparison, low arousal items were recalled well at 2 minutes (approximately 45% recalled) but dropped to 20 per cent recall after 20 minutes delay and continued to decline over 45 minutes, next day and 1 week recall sessions. On the whole the phenomenon appears to be robust (see Eysenck, 1977 for a review of early research in this area). This effect has been found to be replicable with nonsense syllables also (Kleinsmith & Kaplan, 1964). The original results were interpreted in terms of Walker's action decrement theory (1958), which proposes that a memory trace will be subject to initial inhibition in order to protect it during the initial stages of consolidation. This inhibition makes early retrieval difficult but ensures enhanced consolidation in the long term.

Other early studies, similar to the Kleinsmith and Kaplan design have attempted to exert experimental control over the assignment of items to high or low arousal categories. This control has been achieved by pairing some items with white noise because white noise has been found to increase levels of physiological arousal.

(Magoun, 1963). The majority of early paired associate paradigms demonstrated the incubation effect (Berlyne et al, 1965; McLean, 1969). However, when a different learning and recall method was employed, the incubation effect found with the paired associate method often either disappeared or was reduced. For example, several early studies found that high arousal facilitates immediate recall (Corteen, 1969; Maltzman et al., 1966). This indicated that the 'growth' in memory performance over time for high arousal items may not be robust across memory methods. The paired associate *method* appears to produce results in line with the incubation hypothesis such that a 'cross over' effect appears to be evident in memory performance for high and low arousal items over time (see Figure 2.1). The cross over effect is when high arousal items, when tested immediately are remembered *worse* than low arousal items but after a period of time this position reverses such that high arousal items are remembered *better* than low arousal items.

However, the use of different learning paradigms (i.e. free recall or recognition) has produced results which often do not show the pronounced 'cross over' effect in memory performance (Corteen 1969; Schwartz 1974; Wesner, 1972). Nevertheless, regardless of the size of the interaction, many studies have found an interaction between arousal and retention interval such that memory for high arousal items increase with time and memory for low arousal items decreases with time.

Other research addressing the phenomenon of incubation is based on the seminal findings of Kleinsmth and Kaplan (1963, 1964) but uses a more inferential method of manipulating arousal and so will be briefly reviewed here. A series of studies in the 1960s and 1970s assumed that the arousal levels associated with the

personality variables of introversion and extroversion differed. This assumption was based on evidence suggesting that introverts are more highly aroused than extroverts on the EEG (Gale 1973). This led to a series of studies in which groups made up of 'introverts' as classified on the Eysenck Personality Inventory were classified as a 'high arousal' and 'extroverts' as 'low arousal'. When classifying arousal in terms of a personality type, Howarth & Eysenck (1968) tested recall of paired associates at retention intervals of up to one day. Results indicated that the memory of extroverts (i.e. 'low arousal') was superior to introverts ('high arousal') at the short retention intervals but inferior to introverts at the long intervals i.e. similar to the Kleinsmith and Kaplan findings. Furthermore, Schwartz proposed (1975) that arousal enhances retention based on the physical properties of a stimulus (e.g. phonemic properties) but impairs retention of semantic attributes. In two studies in 1975 Schwartz assigned participants to different arousal groups based on their extroversion and introversion scores. All participants learned paired associate lists where the response words were either all phonemically similar or all semantically similar. The interaction between introversion, extroversion and list type was highly significant. This interaction was such that high arousal participants were not adversely affected by semantic similarity; in other words they made few errors on the semantic list (because, arguably, they were concentrating on physical attributes). In contrast, low arousal participants were not adversely affected by phonemic similarity [because perhaps they were concentrating on semantic characteristics. (Schwartz 1975a,b)]. Another study suggesting that high arousal leads to storage of more information about the physical properties of a stimulus was carried out by Hamilton et al (1972).

Without the use of personality variables, they found that arousal produced by white noise produced a significant improvement over the no noise condition in recall of paired associates when the paired associates were presented in a fixed order but not when the paired associates were presented in a random order. Thus, arousal benefited memory when the physical properties of the stimuli were kept in a constant fixed order but not when they were randomly presented. This suggests that, in terms of influencing memory performance, arousal may interact with the properties of the stimulus. The order of presented stimuli may contribute to enhanced recall under conditions of arousal rather than aspects of the stimuli themselves. This methodological effect on memory could be controlled for by randomly presenting to-be-remembered stimuli.

In summary, memory performance for high arousal items at immediate recall is not always necessarily *worse* than memory for low arousal items at immediate recall (as is the case in studies of classic 'cross over' incubation effects). Nevertheless, the finding that incubation occurs with high arousal items seems robust across paradigms. Interpretation problems exist when using personality variables to define groups categorised also in terms of arousal. It is difficult to determine the degree to which arousal affects performance in the studies employing introverts and extroverts. Differences in performance could be due to some other idiosyncratic difference in learning/memory between the two personality types. Nevertheless, these studies claim to support the 'cross over' incubation effect and also indicate (along with studies using more direct measures of arousal) that high

levels of arousal may lead to the storage of more information about the physical properties of a stimulus rather than the semantic properties of a stimulus.

More recently, the incubation study has been cited as fundamental to an interpretation of the impact of arousal on memory (Christianson, 1992; Heuer & Reisberg, 1992). Fundamental to a consideration of how arousal impacts on memory functioning is an understanding of what parts of an emotion-eliciting stimulus are remembered. Some researchers propose that central (or gist) information is better recalled than more peripheral information under conditions of high arousal. The apparent contradictory findings relating to the direction of arousal's impact on memory is thought to be because some studies have assessed central or gist information while other studies have assessed more peripheral information (Christianson, 1993). Heuer and Reisburg (1993) interpret the evidence such that central detail information is remembered initially poorly and improves with the passage of time. The Kleinsmith and Kaplan study thus appears critical to this interpretation of research findings in the field of emotional memory in man.

2.1.2. Memory consolidation and the brain: animal evidence

Studies of memory consolidation in both humans and animals suggest that structures in the medial temporal lobe such as the hippocampus and the medial and diencephalic regions (Tulving & Markowitsch 1997) may be involved in the laying down and storage of to-be-remembered stimuli. A number of animal studies support the theory that temporal lobe structures are involved in consolidating memory. For

example, rats exhibit a time dependent increase in hippocampal neural cell adhesion molecule between 12 and 24 hours following an initial passive avoidance learning trial (Fox et al 1995). Gutierrez Figueroa et al (1997) have found that lesioning the entorhinal cortex before and after training on a two-way shuttle avoidance task impairs task performance. Task performance requires the building of memories acquired in successive sessions; this requirement would need to involve some form of memory consolidation. Other studies in the area suggest that the amygdala may strengthen hippocampal dependent memory consolidation for an emotionally engaging task in a post encoding time window (McGaugh et al, 1992; Packard et al, 1994). This indicates an integrative role for these structures in the process of consolidating arousal-mediated memory.

One such study involved implanting canulae into CA1 field of the hippocampus, the amygdaloid nucleus and the enthorinal cortex and posterior parietal cortex of adult male rats (Zanatta et al 1997). These rats were then trained in a step down inhibitory avoidance task. At certain time lags after training (0, 30, 60, 90 minutes) animals received either saline or muscimol (GABAergic agonist) micro infusions. Testing of retention after 24 hours found muscimol administered to the hippocampus and amygdala immediately after training hindered performance in the 24-hour retention test. This effect was not found at the 30-minute administration to these structures. Interestingly, when muscimol was administered to the entorhinal cortex and parietal cortex, retention performance was only hindered if the administration had been 30, 60 or 90 minutes after training (60 and 90 for parietal cortex). These findings can be interpreted in the light of Walker's action decrement

theory mentioned above in so far as the initial stages of consolidation may occur in the hippocampal and amygdaloid regions. Cortical regions may play a role in later consolidation.

However, other animal studies have suggested that the hippocampus and not the amygdala may be involved in long-term storage of an arousing event (Bevilaqua et al 1997). Indeed some researchers argue that memory should be viewed as a change in synaptic neural connectivity in many different brain systems, rather than in particular localised structures.

2.1.3. Recent human studies support the incubation effect: LaBar and Phelps 1998

Human studies of arousal mediated memory consolidation (LaBar & Phelps, 1998) have provided further evidence for the importance of the medial temporal lobe structures in the formation of memories over time. LaBar & Phelps (1998) studied unilateral temporal lobectomy patients and healthy controls performance on an adaptation of the Kleinsmith and Kaplan (1963) paradigm. Participants were required to rate both taboo and neutral words on an arousal scale while Skin Conductance Responses (SCR's) were monitored. Recall was assessed immediately and also after a one-hour delay. Control participants produced an increase in memory for the taboo words over time and a decrease in neutral memory; this was not the case for the lobectomy group. This effect was exhibited even though all participants (both lobectomy and controls) generated enhanced SCR's and subjective ratings to the taboo words at encoding. The authors claimed that this provided good

evidence for the role of medial temporal lobe structures in memory consolidation for arousing events in man. They inferred that the integrative function of the amygdalo-hippocampal structures found in animal studies also occurs in the human brain.

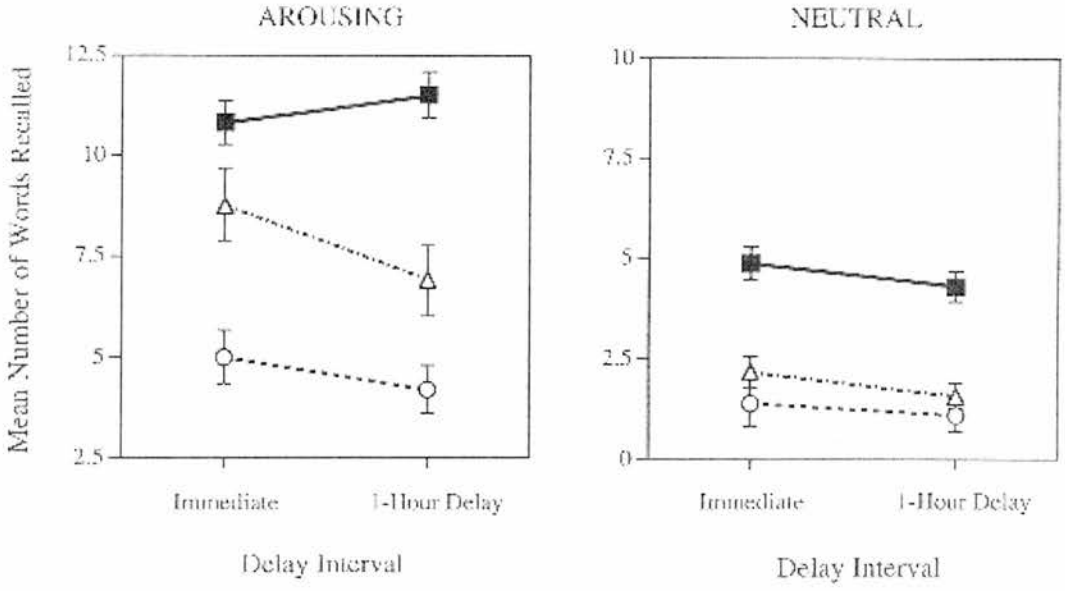


Figure 2.2 is reproduced from LaBar and Phelps (1998). The figure shows the word recall performance of controls (black line with square symbols), and temporal lobectomy patients (broken line with circular symbols = left temporal lobectomy group, broken line with triangular symbols = right temporal lobectomy group) for arousing words (left hand box) and neutral words (right hand box) assessed at two recall intervals (x axis). The control participants show an increase in memory performance for arousal words when assessed 1hour following presentation (left hand box) compared to an immediate assessments. However, they show a decrease in memory performance for neutral words over the same interval (right hand box).

2.1.4. Criticisms of current research findings

In the light of some of the evidence outlined above, it would appear that structures such as the amygdala and hippocampus might play a role in initial consolidation in man. However, a number of differences exist in the human literature

that make it difficult to confidently conclude that incubation occurs for arousal eliciting material in humans.

2.1.4.1. The Kleinsmith and Kaplan study was a between- participants design.

The Kleinsmith and Kaplan (1963) study compared memory performance for the same series of 8 word stimuli over five recall intervals, however their study could not address the degree to which an *individual* subject's memory performance changed over time. A sub-group of their participants had a memory assessment immediately; a different sub-group had a memory assessment after 20 minutes, yet another sub-group had a memory assessment after 24 hours etc. LaBar and Phelps (1998) used more than one group of participants because they were assessing between-group differences in memory performance between brain-damaged patients and controls. Nevertheless, within these groups, LaBar and Phelps assessed the same participants at two different recall intervals (immediate and one hour). It is arguably more appropriate to design within- participants studies to best test hypotheses relating to memory changes over time.

2.1.4.2. Paired associate learning in the Kleinsmith and Kaplan study (1963): memory was assessed for the numbers attached to words, not the words themselves.

The results of the Kleinsmith and Kaplan study (1963) are surprising. In the first instance, it is remarkable that memory performance for a series of 8 words

assessed immediately following presentation should not be at ceiling. Kleinsmith and Kaplan however reported that less than 10 per cent of the 'emotional' words were correctly recalled immediately. There were four of these high arousal words presented in total, indicating that participants recalled 0 or 1 word on average. One explanation for the suprisingly poor performance on the test stimuli was that the learning task was difficult. Participants would first be presented with the to-be – remembered word (e.g. "EXAM"). They would then be presented with the word and a single digit number (e.g. "EXAM – 9"). This would be followed by two colour box filler items (participants had to name the colours in these two successive colour grids before the next stimulus word was presented). During recall, participants were not, in fact, required to recall any words at all. They were shown the words that had been presented before and were asked to produce the *number* that had been associated with a given word previously. So, for the example given above, a subject would be shown the word "EXAM" and the correct response would be to say "9". It is clear that this same procedure was used for all participants (regardless of recall group). Therefore, using this method elicited surprising differences in number recall over time. The results of this study indicate that participants are less likely to recall a number attached to an arousing word when tested immediately as compared to the number attached to a neutral word when tested immediately. This result could be interpreted as evidence to suggest that memory for the peripheral elements of an emotional stimulus (i.e. the number attached to an emotional word) will not be well remembered initially. This could lead to the suggestion that memory for emotional material is more 'focused' (Easterbrook, 1969). Perhaps a recall assessment for the

emotional word rather than peripheral numbers would have lead to a very different pattern in memory performance in the Kleinsmith and Kaplan (1963) study?

2.1.4.3. LaBar & Phelps (1998) employed word recall with more words, but these words were not matched for frequency of occurrence in the English language

One improvement on the original paired recall method is to adopt a larger number of words in the study (thereby avoiding the possible effects of ceiling) and ensuring that participants recall words only and not peripherally presented numbers.

LaBar and Phelps used a considerably larger number of items to be remembered than did Kleinsmith and Kaplan (40 vs. 8 respectively) in their human study. They also assessed memory for the words 'immediately' and at an hour interval [as opposed to the 2, 20, 45 minute, 1 day and 1 week interval used by Kleinsmith and Kaplan (1963)]. However, LaBar and Phelps failed to match their 'taboo' and 'neutral' words in terms of frequency of occurrence in the English language.

It is possible that with more matched items, with consolidation intervals similar to those employed by Kleinsmith and Kaplan, and a test of free recall memory (rather than the paired associate method) the same increase in percentage of 'high arousal' words remembered may not be found. Early evidence indicates that the 'cross over' incubation effect may be dependent on experimental paradigms rather than underlying emotional memory mechanisms. In particular, it is possible that matching taboo and neutral words for frequency of occurrence in both written and

spoken English would provide a fairer test of the consolidation hypothesis. It is also possible for example, that higher evoked GSR to words categorised as taboo than words categorised as neutral reflect differences other than arousal value inherent in the stimulus. Items which differ in terms of GSR, may also differ in terms of meaningfulness and familiarity. One theory proposed by Eysenck (1977) is that those items producing large GSRs are the ones that are processed more fully and to the greatest depth. If this is the case, a neutral word (e.g. 'enigma') occurring as often in the written and spoken language as a word considered taboo (e.g. 'bastard') may require a similar degree of 'processing effort' (Kahneman, 1973) and perhaps result in a similar 'depth of processing' (Craik and Lockhart, 1972). The neutral word should, according to the theory proposed by Eysenck (1977), produce similar levels of GSR to the taboo word. In summary, the LaBar and Phelps result may have been due to the taboo words being less familiar, or frequent than neutral words, rather than differences in emotional impact.

2.1.5. The present study addresses shortcomings of previous research

The nature of the stimuli employed in studies of the effects of arousal on memory may explain why the incubation effect in man is as replicable as it appears to be, the effect being that low arousal words are remembered initially well and that memory declines over time, while taboo words are remembered initially poorly but memory increases over time. Removing the differences other than 'degree of emotional arousal' that separate the two sets of words (e.g. frequency, length,

construction) may well result in the removal of the incubation effect also. Accordingly, it is predicted that matching taboo and neutral words for frequency of occurrence will result in a consistently higher rate of recall for the taboo words and a consistently lower rate of recall for the neutral words, immediately, at half an hour interval, at 1-day interval and at one-week interval. It is suggested that the incubation effect may be an artefact of shortcomings of prior research. The words used in the current study were therefore matched for frequency of occurrence in the English language and classified for analysis in three different ways:

a) Words were predetermined as either 'taboo' or 'neutral' based on arbitrary classifications employed in previous studies using these stimuli (LaBar & Phelps 1998). Memory could be assessed for words that were pre-classified as either taboo or neutral
b) Words were classified as taboo and neutral via analysis of the verbal ratings of arousal assigned to them by participants. Memory could be assessed for words that were classified as receiving an above or below threshold verbal rating of arousal.
c) Words were classified as taboo or neutral via GSR responses at the time of their presentation. Memory could be assessed for words that were classified as receiving an above or below threshold GSR.

2.1.6. Hypothesis

1. Memory for words pre-classified as 'taboo' or 'above a verbal rating threshold' or 'above a GSR threshold' will be recalled consistently better than words pre-classified as 'neutral' or 'below a verbal rating threshold' or 'below a GSR threshold'.

2. This consistently superior pattern of recall for above threshold words will be maintained when assessed immediately, at 30 minutes delay, at 24 hours delay and at one-week delay, i.e. there will be no incubation over time.

2.2. Method

2.2.1. Participants

Twenty-four participants took part in the study [13 females, 11 males; mean age (SD) = 27.13 (10.78)], similar to the number of control participants employed by LaBar & Phelps (1998). They were recruited following poster and E-mail advertisement campaigns at the Universities of Stirling and St Andrews in Scotland. All participants read and signed an informed consent sheet and were paid a total of £12 for participating. Participants consisted of lecturers, research fellows, undergraduate and postgraduate students. Participants were not told that the study

aimed to assess memory but rather that a series of physiological and verbal responses were being sought for a series of words to be included in a corpus of words to be used in future research.

2.2.2. Apparatus and Materials

On arrival participants were required to view and read aloud a series of 40 words, which varied in their affective nature. Twenty of the words used in the study reported here were identical to the 'taboo' words collected by LaBar and Phelps at Yale University (Phelps & LaBar, 1998), for use in studies of memory impairment after unilateral temporal lobe section (see Appendix 1.). In addition, a further list of 20 neutral words matched with the taboo words for frequency of occurrence in the English language was used in this present study (see Appendix 1). A number of non-verbal tasks were used in the current study as filler/distracter items between immediate and 30 minute delayed recall tasks in the initial session. These included the following items taken from The Wechsler Adult Intelligence Scale – Revised [WAIS-R (Wechsler, 1981)]: The Block Design task, The Object Assembly Test, the Picture Completion Task and The Picture arrangement task. In addition to these, participants were required to copy the complex figure used in the Rey - Osterrieth complex figure test (Rey, 1941; Osterrieth, 1944) while imagining it rotated through 90 degrees in a clockwise or anti clockwise direction. These tasks were used simply as distracters and were not included in subsequent analyses.

2.2.2.1. Words

A list of 20 neutral words was collected for this study from The British National Corpus of words currently used in both written and spoken English (Kilgarriff, 1997). Kilgariff obtained frequency values for a collection of approximately seven thousand words from the corpus (for more information on these lists see website address http//www.itri.brighton.ac.uk/~Adam.Kilgarriff). For the purposes of this study, frequency of occurrence data was gathered from the Kilgarriff lists for the taboo words presented in the LaBar and Phelps study (1998). Words were then chosen from the Kilgariff lists, which matched those, presented by LaBar and Phelps for frequency and length and construction (see Appendix 1 for a list of these words and their frequency values). All words were presented in black Helvetica font on a white background screen of an Apple Macintosh Power PC (4400/200). The words were presented for a period of 5 seconds in random order using SuperLab Pro software (Cedrus Corporation, 532 E Maryland, Suite B3, Pheonix, AZ 85012. USA). In addition to the presentation of the 40 stimulus words, four additional words were used, two at the beginning and two at the end of the randomised presentation of 40 words to reduce further serial order effects in free recall. These 'buffer words' were not included in any analysis.

In addition to viewing and reading aloud the list of 44 words, participants were required to view and read aloud a series of 80 four-cell colour grids, which

were presented using identical apparatus and software as described above. The naming of colours was included as a filler task between each word presentation. The colours blue, red, green, black yellow and orange were randomly combined in ten colour grids, which were used as filler items (two colour grids, one after the other were presented for 5 seconds each following each 5 second, single word presentation). Participants were required to name the colours seen in any order.

The words themselves (total n=40) were classified in three ways for the later analyses of memory performance:

a) Words were predetermined as either 'taboo' or 'neutral' based on arbitrary classifications employed in previous studies employing these stimuli (LaBar & Phelps, 1998). Memory could then be assessed for words that were classified in advance as conventionally either taboo or neutral. When words were pre-determined in this way, the dependent variable was expressed as the percentage of the total number of taboo words recalled at each time interval and the percentage of the total number of neutral words recalled at each time interval. In principle, participants could produce 100% correct performance for neutral words and 100% correct performance for taboo words.

b) Words were classified via verbal ratings of arousal (1-4) assigned to them by participants. Memory could be assessed for words that were classified as receiving an *above, below or equal to* threshold verbal rating of arousal. The threshold was defined as the median split of total verbal ratings of arousal (1-4) to words recorded from all participants and ranked in mean order. This verbal 'threshold' was than applied to each individual participant's ranked verbal

responses to words. The dependent variable, the percentage of words actually recalled that were above the threshold, could be calculated for each individual subject, and the percentage of words recalled that were below the threshold could be calculated for each individual subject. The verbal rating threshold (ranked word 20 mean verbal rating + ranked word 21 mean verbal rating divided by 2) was 1.92. Therefore, words receiving a rating of 2, 3 or 4 were considered above the verbal rating threshold and words receiving a rating of 1 were considered below the verbal rating threshold.

c) Words were classified via GSR responses at the time of their presentation. Memory could then be assessed for words that were classified as receiving an *above, below or equal to* threshold GSR. GSR threshold was defined as the median split of total GSR change from baseline mean responses to words ranked in mean order. The same procedure was followed as for the verbal threshold but for the GSR classification. Words were ranked in order of the mean GSR response to them from all participants and the median of this rank was taken as the GSR threshold (ranked word 20 mean GSR + ranked word 21 mean GSR divided by 2 = 2.3 mmhus). This threshold was then applied to each individual's ranked responses to words. The percentage of words actually recalled that were either above or below the GSR threshold (the dependent variable) could then be calculated. One subject produced a GSR response to a word that was at the threshold of 2.3 mmhus. This word was included in subsequent analysis as an above threshold word.

2.2.2.2. Physiological response (GSR)

The GSR is "a phasic measure of eccrine sweat gland activity and a reliable autonomic indicator of sympathetic nervous system" arousal (Williams & Evans 1980). Baseline and ongoing galvanic skin response was recorded using a set of two Biopac Ag-AgCl electrodes, which incorporate moulded housings for finger attachment. An application of saline electrolyte in a non sensitising aqueous polymer gel was made to the finger tip pads of the index and second finger and electrode placement made so that electrolyte covered the cavity of each electrode. The site was first cleansed using Hibiscrub cleanser, an abrasive pad was used to remove excess dirt from the grain (when dry) and an alcohol pre-injection swab was then used to remove any small amounts of dirt removed by the abrasive pad.

Electrodes were attached to a Biopac Student Lab Pro system (Model MP30 Biopac Systems Inc., Linton Instrumentation, Norfolk) acquisition unit. In conjunction with an Apple Macintosh computer, the Biopac student Lab is a system for acquiring continuous data. It can perform various recording tasks from high-speed acquisitions (up to 2000 Hz) to long duration acquisitions. For the purposes of this study, a channel for acquiring GSR data was set up with a low pass digital filter (frequency 66.5hz, Q=0.5). The sample rate from this channel was 200 samples per second. Measurements were taken following stimulus onset and ceased at stimulus end. The GSR value for analysis in this study was the change from mean baseline value (micro mhu). The average response peak following each stimulus presentation was recorded and the average baseline value (during the baseline period) was

subtracted from that average peak value. – See below for description of baseline procedure.

During recording of GSR, external noise was kept to a minimum. Any noticeable noise from outside the laboratory that occurred during stimulus presentation was noted and marked on the GSR trace. When such markers were placed on the trace during stimulus presentation the corresponding response was excluded from analysis.

2.2.3. Procedure.

Initially, prospective participants were invited to attend an informal first meeting in which they were issued with a detailed information sheet and informed consent sheet. Dates for three subsequent meetings were arranged if they agreed to continue.

During the initial encoding session, participants were then attached to the Biopac acquisition unit and required to perform a number of tasks in order to obtain a baseline and to allow familiarisation with the electrode placement. These tasks required participants to read aloud (90 sec.) and read silently (90 sec.). The session also included a relaxation period with eyes closed (90 sec.) and then eyes open (90 sec.). Eventual baseline measures were taken by averaging GSR activity over the final 90-second 'relax with eyes open' period of baseline activity.

Participants were then exposed to the 40 word stimuli in a random order. Each word appeared for 5 seconds, followed by each filler item colour array for five

seconds each. A two-second blank screen was presented between the end of the filler array and the presentation of the next randomised word.

During presentation of each word, participants were required to rate "how arousing" the word was when they saw it. This rating was made on a four-point scale (1=unaroused/ 4 = high aroused). Instructions were identical for each subject and were as follows:

"If you felt stimulated or excited or frenzied or jittery or wide awake or aroused when viewing the word, then please call out the number 4. If you felt relaxed or calm or sluggish or dull or sleepy or un-aroused when viewing the word then call out the number 1 if you felt somewhere in between these two extremes then call out the numbers 2 or 3"

These instructions are similar to those employed in the image rating studies carried out by Lang and colleagues using the self assessment manikin to rate subjective states of arousal, dominance and valence (Lang et al. 1999. Technical reports A-4, The Center for Research in Psychophysiology, University of Florida). Immediately after the presentation of the stimulus set, participants were required to verbally recall any of the words presented; instructions to all participants were kept constant and were as follows:

"Please try and remember any of the words you have just seen. Please take as long as you like to do this, when you think that you have remembered all the words you can, please say 'that is all I can remember'. Remember that we do not expect you to

get a large number of words, just try and do the best you can, and do not worry about repeating any of the words or getting them in the same order in which they were presented"

A period of thirty minutes followed the first free recall exercise during which participants were required to complete a number of non - verbal filler tasks taken from the WAIS-R in random order. These filler tasks are described above. The initial session ended with a further free recall period in which participants were again urged to recall as many of the words as possible that they had been shown half an hour before.

The second recall session took place the following day at the same time, the last session 1-week later, again at the same time. Deception was employed so as to reduce possible rehearsal between the first and second, and second and third sessions. At the end of the first session, all participants were given the following information:

"During tomorrow's session, we will want you to rate a new and different set of words for the corpus following the same procedure as today. It is important that other potential participants do not know about the words. If they expect certain words, their responses may be different. Please try not to tell anyone about any of the words"

At the end of the second session participants were given the following information concerning the final session to take place seven days from the second session:

"Next week we will present some more words to you on the computer, the same words as you saw initially (during the first session yesterday). We want to see if your physiological reaction to these words is consistent at the beginning and end of the entire procedure. One possibility is that today's session and yesterday's session increased familiarity to the words and therefore your physiological response may be diminished at one-week interval. As we said before, please remember not to tell others about the words as this may affect the results of the study"

The statements concerning procedure given to participants at the end of the first and second session concerning the second and final sessions were deceptive. The aim of the second and final third session was to again assess free recall for words presented in the initial session. Deception was employed to reduce the possibility of rehearsal between first and second and second and third sessions affecting free recall performance. The deception prior to the second session led the participants to believe they would be viewing a new set of words. The deception prior to the final session led the participants to believe they would be having GSRs measured, not memory. Final debriefing included detailed questions concerning degree to which participants expected the immediate, 30-minute, 24-hour and 7 day recall. Three participants expected a memory test at either 24 hours or 7-day sessions. These participants' data were therefore excluded from analysis.

During the second (24 hour) and third (7 day) sessions participants were initially re-connected to the Biopac acquisition unit and required to perform the baseline tasks. This was in order to maintain the deception that the second session would involve the same procedures as the first session but would involve the presentation of a new set of words. The aim of the second session was to assess memory for the original list of words for the third time. Participants were asked to freely recall words in an identical procedure to the one carried out on the initial two free recall sessions (immediate and 30 minute delay). After the 1 week free recall task participants were required to rate the series of 40 presented words embedded in a further 10 'new' words. The words were to be rated on a 7-point familiarity scale (from 1 = 'not at all familiar' to 7 = 'very familiar')

2.2.4. Design and Analysis

This study was a repeated measures, within-subject design with four levels of the within-subject variable, 'time' (level 1: Immediate recall; level 2: 30 minute recall; level 3: 24 hour recall; level 4: 7 day recall) and two levels of stimulus category (taboo and neutral). Bivariate correlations were conducted on GSR responses to words, verbal rating of words and participants rating of familiarity at one-week interval. Repeated measures ANOVA was conducted on the percent recall scores for words using the three methods of classification: a) predetermined taboo or

neutral. b) Above or below GSR threshold of 2.3 micro mhu change from baseline (median split) or c) Above or below verbal rating threshold of 1.92 (median split).

In all the experimental chapters of this thesis, if any within-participants variable had more than two levels, Mauchly's test of Sphericity was conducted on the within-subject variable. The significance of Mauchly's 'W' indicates that the assumption of equivalent correlations between the variables in the ANOVA is not supported. In the event of this analysis being significant, and according to current convention (Brace et al., 2000, p192), a multivariate criterion of Wilks' Lambda was adopted for the within-subject factor in the analysis. In the event of this analysis being non-significant, then the univariate results were reported.

2.3. Results

Overall, regardless of classification, participants recalled 9.25 (sd: 3.05, range: 4 – 16) words immediately following the presentation. 9.88 words were recalled after 30 minutes (sd: 3.71, range: 4 – 17), 9.17 words were recalled after 24 hours (sd: 3.56, range: 4 – 15) and 8.17 words were recalled after 7 days (sd: 3.13, range: 4 – 16).

2.3.1. Correlation between verbal ratings, Galvanic Skin Responses and memory measures.

Initial correlational analyses tested for relationships between Galvanic Skin Responses (GSR) at the time of word presentation, verbal ratings of arousal (1-4) at the time of word presentation, total words recalled over all recall intervals and familiarity ratings (1-7) at presentation of 40 target words and 40 distracters at the end of the one-week recall session. There was no significant correlation between GSR and verbal rating of arousal both recorded at presentation (Pearsons R = .09, p = .70). There was no significant correlation between the total number of words recalled over all recall intervals and galvanic skin response to words at presentation (r = .18, p = .39). There was no significant correlation between verbal ratings of arousal at exposure and familiarity rating at one week (r = .06, p = .78) and between GSR at exposure and familiarity ratings at one week (r = .09, p = .67). No significant correlation was found between verbal ratings of arousal at presentation and memory performance at the 4 intervals and no significant correlation was found between words categorised as taboo or neutral and memory performance at the same 4 intervals. Therefore, there was no significant relationship between memory performance and category of word (taboo/neutral), subjective ratings of the to- be-remembered words and GSR response to words.

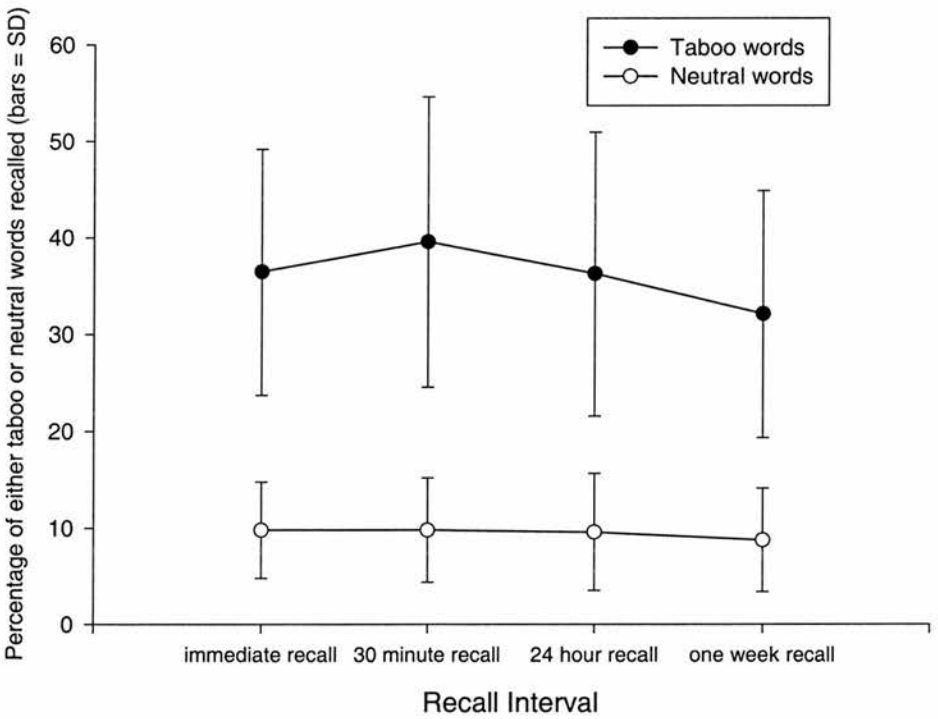
2.3.2. Memory performance for words pre- classified as 'taboo' or 'neutral'

(See Figure 2.3.)

A two-way within-participants ANOVA was conducted to evaluate the effect of predetermined word classification (from LaBar & Phelps, 1998) and time interval between recall assessments on verbal free recall memory scores. The dependent variable was the percentage of taboo or neutral words recalled. The within-subject factors were (a) word classification with two levels ('taboo' or 'neutral) and (b) time interval between presentation of the to-be-remembered words and memory assessments (4 levels - immediate, 30 minute, 24 hours and 7 days). The within-subject factor 'interval' had more than two levels and accordingly, Mauchly's test of Sphericity was performed on this variable and this variable in interaction with word classification. The test of sphericity was significant for 'interval' only [Mauchly's W (5) = .55, p = .02]. Accordingly, a multivariate test of Wilks' Lambda was adopted for the within-subject factor 'interval' in the analysis of words classified as 'taboo' or 'neutral'. The word classification effect was significant [F (1, 23) = 132.48, p = .01]. The effect of recall interval was significant [F (3, 21) = 9.2, p = .01] and the word classification by recall interval interaction was significant [F (3, 21) = 4.5 p = .01] (see Figure 2.3). Taboo words were recalled consistently better than neutral words. Further analysis of the interaction (separate repeated measures ANOVA on neutral words only and taboo words only) revealed that there was no significant effect of recall interval for neutral words [F (3, 21) = 1.21, p = .33]. By contrast,

there was a significant effect of time for taboo words [F (3, 69) = 5.55, p = .01]. Simple within subject contrasts revealed that recall performance on the immediate test was greater than the recall performance following one week [F (1, 23) = 5.66, p = .03]. Difference contrasts revealed memory performance after seven days was inferior to memory performance after 24 hours [F (1, 23) = 19.46, p = .01]. Therefore normal decay occurred for taboo words, which were consistently better recalled than neutral words.

Figure 2.3. Percentage of pre-defined taboo and neutral words recalled at 4 intervals



[Significant effect of word classification, recall interval, and a significant word classification by recall interval interaction]

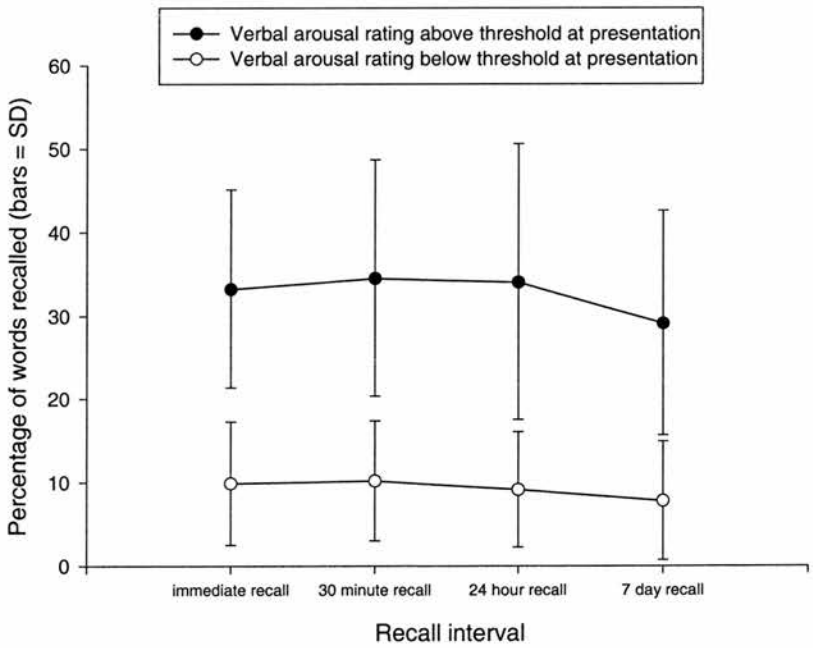
2.3.3. Memory performance for words classified as above and below a verbal rating threshold

(See Figure 2.4.)

The 40-word set was also classified for analysis in terms of whether participants rated words at presentation as above or below the median split verbal arousal rating threshold of 1.92 (see design and analysis section for the determination of threshold values). The mean number of words that were above the verbal rating threshold was 23.5 (sd: 6.74, range: 12 – 40). The mean number of words that were below the verbal rating threshold was 16.5 (sd: 6.73, range: 0 – 28). A two-way within-participants ANOVA was conducted to evaluate the effect of verbal rating and time interval between recall assessments on verbal free recall memory scores. The dependent variable was the percentage of words freely recalled. The within-subject factors were (a) verbal rating, with two levels (above or below verbal rating threshold) and (b) time interval between presentation of the to-be-remembered words and memory assessments (4 levels - immediate, 30 minute, 24 hours and 7 days). Mauchly's test of Sphericity was not significant for the within-subject factor 'interval' [W (5) = .75, p = .28] but was significant for the interaction between interval and word classification [W (5) = 12.68, p = .03]. Therefore, the multivariate criterion of Wilks' Lambda was used to test the interaction only. The effect of verbal rating was significant [F (1, 23) = 98.70 p = .01] as was the effect of recall interval [F (3, 69) = 6.19, p = .01]. The verbal rating by interval interaction was not significant [F (3, 21) = 1.06 p = .39 (see Figure 2.4)]. To follow up the significant main effect of recall interval, four paired sample t-tests were conducted

on the entire sample of the words rated as above the verbal rating threshold. A greater percentage of words rated as above threshold were correctly recalled immediately [t (23) = 2.81, p = .01], after 30 minutes [t (23) = 2.72, p = .01] and after 24 hours [t (23) = 2.91, p = .01] than were recalled after seven days. No other comparisons were significant relating to words rated as above the verbal rating threshold. Four paired sample t-tests were conducted on the words rated as below threshold in the verbal rating exercise. A greater percentage of words rated as below threshold were correctly recalled after 30 minutes than after seven days [t (23) = 3.04, p = .01]. No other comparisons were significant with respect to the words rated as below the verbal rating threshold. Again, there was a clear word category effect but no evidence of an incubation effect.

Figure 2.4. Percentage of words classified as above and below a verbal rating threshold recalled at 4 intervals.



[Significant effects of verbal rating and recall interval]

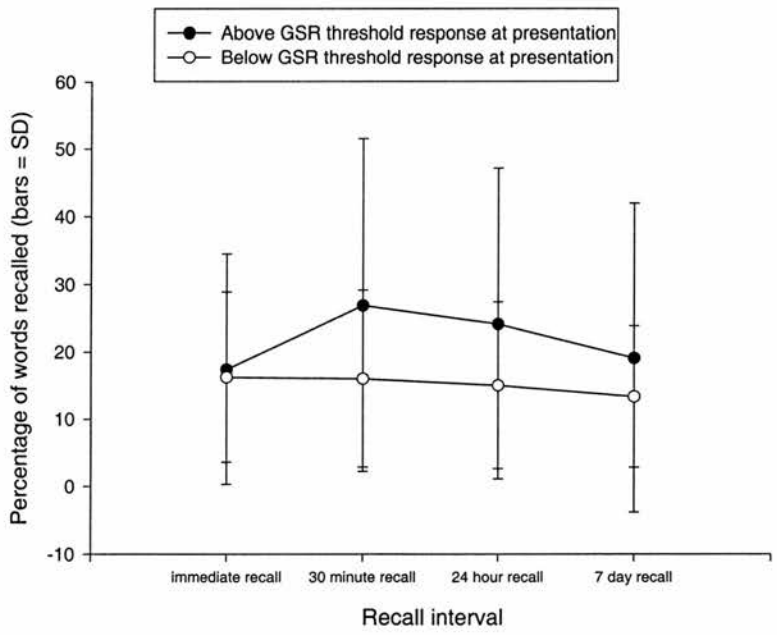
2.3.4. Memory performance for words classified as above and below GSR threshold

(See Figure 2.5.)

The 40 word set was also classified for analysis in terms of whether participants produced GSR responses at the time of word presentation that were above or below median split of 2.3 micro mhu [change from baseline (see design and analysis section for the determination of threshold values)]. The mean number of words classified as above the GSR threshold was 17.29 (sd: 16.49, range: 0 – 40). The mean number of words classified as below the GSR threshold was 22.42 (sd: 16.83, range: 0 – 40). A two-way within-participants ANOVA was conducted to evaluate the effect of GSR and time interval between recall assessments on verbal free recall memory scores. The dependent variable was the percentage of words freely recalled. The within-subject factors were (a) GSR threshold, with two levels (above or below threshold) and (b) time interval between presentation of the to-be-remembered words and memory assessments (4 levels - immediate, 30 minute, 24 hours and 7 days). Mauchly's test of Sphericity was not significant for the interval by word classification interaction [W (5) = .62, p = .07] but was significant for the within-subject factor 'interval' [W (5) = .28, p .01]. Therefore, the multivariate criterion of Wilks' Lambda was used to test the effect of interval only. The effect of GSR threshold was not significant [F (1, 23) = 2.18, p = .15]. The GSR threshold by interval interaction was also not significant [F (3, 69) = 2.18 p = .10]. However there

was a significant effect of recall interval [F (3, 21) = 4.38, p = .02 – see Figure 2.5]. To follow up the significant main effect of recall interval, four paired sample t-tests were conducted on the total group to assess differences in memory performance at the four time intervals (this was irrespective of GSR because the GSR effect was not significant). In total, a greater percentage of words were correctly recalled after 30 minutes [t (23) = 3.70, p = .01] and after 24 hours [t (23) = 2.85, p = .01] than were recalled after seven days. No other comparisons were significant with respect to recall interval.

Figure 2.5. Percentage of words classified as above and below GSR threshold recalled at 4 intervals.



[Significant effect of recall interval only]

2.4. Discussion

2.4.1. An emotional memory effect but no evidence for incubation: Arbitrarily classified words.

The 40 - word stimulus set employed in this study contained 20 words that had been arbitrarily classified as taboo and 20 words that were matched for length and frequency to the taboo words but were classified as neutral. An analysis of free recall performance immediately following word presentation, 30 minutes following word presentation, 24 hours and 7 days following word presentation revealed significant differences between recall intervals for words classified as taboo and no significant differences between intervals for words classified as neutral (Figure 2.3.). Free recall performance was consistently superior for 'taboo' words as compared to 'neutral' words over all recall intervals and there was no evidence of an incubation effect over the recall intervals for taboo words (see Figure 2.3.). The taboo words showed evidence of normal decay over time. The study carried out by LaBar and Phelps (1998) used the same number of words as used in this study. In addition, the 'taboo' words used in the present study were identical to the 'taboo' words used in the LaBar and Phelps study. The LaBar and Phelps study found evidence for incubation effects when controls learned taboo versus neutral words such that memory for taboo words increased when assessed after an hour compared to when memory was assessed immediately, whereas memory for neutral words decreased

over the hour interval. In the present study, when the LaBar and Phelps neutral set were replaced with frequency matched neutral words, we found that taboo words were recalled consistently and significantly better than neutral words. This indicates that the incubation effect seen for free recall of emotional words is not a robust or replicable phenomenon.

2.4.2. The effects on memory of verbal self-ratings of arousal in response to words

The verbal rating of how 'aroused' the participants in the present study felt when seeing a given word presented on the screen produced differences between above and below median split threshold words in terms of verbal ratings and recall intervals on memory performance. If a subject rated a word as above the verbal rating threshold they would be more likely to remember it when assessed over all time intervals than if they rated a word as below the verbal rating threshold. Words that had received an above threshold rating were consistently better recalled than below threshold words when tested immediately, after 30 minutes, 24 hours and 7 days. However, for the above threshold words, there was no difference in recall rates over the first 3 assessments occurring in the first 24 hours following presentation (see Figure 2.4). Memory performance at these intervals (immediate, 30 minute, 24 hour) was however better than at seven days. This indicates that normal memory decay occurred between 24hour recall and 7-day recall and that a pattern of incubation was not evident in memory assessments occurring over the first 24 hours

for words rated as being highly arousing. For the below threshold words, recall performance after 30 minutes was greater than recall performance after seven days. Again, there was no 'incubation-like' increase in memory performance between the immediate and 30-minute recall test.

This evidence further supports the conclusion that the incubation effect is not a robust one. Not only did we fail to replicate the incubation effect when words were arbitrarily classified as taboo and neutral and matched for frequency of occurrence (compare Figure 2.1 with Figure 2.3.), we also failed to demonstrate incubation when participants themselves rated words with regard to their emotionality (Figure. 2.4).

2.4.3. GSR responses to words do not reliably predict differences in memory performance in this study.

There was no significant correlation between GSR and the total number of words recalled. When words were classified according to whether they had produced above or below threshold GSR values at presentation, a greater percentage of words were remembered after 30 minutes and after 24 hours than after 7 days. It is important to note that there was no significant difference between above and below threshold GSR words in terms of memory performance. Therefore, memory performance decayed after the 30 minute recall assessment for <u>all</u> words, regardless of whether they occurred alongside above or below threshold GSR responses at presentation (see Figure 2.5.).

It would appear therefore that classifying words as above or below GSR threshold produces no significant differences in memory in this particular study. It is not the case that a word that elicits an above threshold GSR was better remembered than a word eliciting a below GSR threshold response.

2.4.4. No 'cross-over' effect found in the current study

The results of the current study demonstrate differences in memory performance for pre-classified taboo words compared to neutral words and for above compared to below threshold verbal emotionality ratings. However, these results are not in line with the dramatic 'cross over' effects in memory performance seen in Kleinsmith and Kaplan's studies (1963; 1964 – see Figure 2.1). Kleinsmith and Kaplan demonstrated that memory for a neutral word was initially superior to memory for taboo words and later reversed so that memory for taboo words was superior to memory for neutral words. Phelps and LaBar (1998) have also failed to demonstrate a 'cross over' effect in memory performance with a healthy adult group (see Figure 2.2). One reason for the difference between the Kleinsmith and Kaplan study (1963) and the results of the current study and that of LaBar and Phelps is that the 1963 study employed 9 words learned and recalled using a paired associate paradigm. This paradigm was not employed in the current study or the LaBar and Phelps's study. It is possible that providing a number cue for recall constitutes the potential for added memory interference compared to free recall, which results in a more marked consolidation effect for arousing words only. Further research could

identify the strength of the consolidation effect using a similar number of to- be-remembered words as used in the current study and that by LaBar and Phelps but learned using the paired associate method.

2.4.5. Potential Problems with this study

2.4.5.1. Within- subject design

Emotionally arousing words (pre-classified or self-rated) were consistently remembered better over time than neutral words in this study. Eysenck (1977) has suggested a number of alternative hypotheses to account for these temporal influences of arousal on memory. One concern is the use of different rehearsal strategies between-groups of participants employed in previous studies, another concerns differing sensitivity to serial position effects, both in terms of memory performance and physiological response. In the current study we employed a within-subject repeated measures design to minimise any between-group differences in memory strategy. Using such a design has the potential for rehearsal between memory testing sessions but avoids the possibility of between-group differences in strategy. The possibility of participants rehearsing was further minimised by the use of deception, which resulted in the majority of participants reporting having not expected memory tests immediately following presentation, at 30 minutes, at 1 day and at 1 week (at debriefing). Those for whom these subsequent memory tests were not a surprise were excluded from the analysis. Fixed order word lists per se have

been shown to effect free recall (Hamilton et al., 1972 – see section 2.1.1.) therefore, it's potential as a confounding variable was minimised in the present study by the random order of presentation of to-be –remembered items and the inclusion of buffer words at the beginning and end of the randomised presentation. Any initial physiological arousal at the beginning of the stimulus presentation associated with for example test-related anxiety, was controlled for by randomised presentation across participants.

2.4.5.2. Within- category priming effects

A further explanation for the main effect of self- rated arousal (Figure 2.4.) found in the current study is that the words, which coincide with higher levels of self-rated arousal form a semantically cohesive group. This 'cohesiveness' may be more apparent in the taboo list compared to the neutral list (e.g. taboo slang names for body parts), profanities or sexual terms). The LaBar and Phelps (1998) study found that healthy adults produced better immediate free recall performance for the words, which were negative in emotional meaning compared to those, which were positive, suggesting that valence as well as arousal is important. Other studies (e.g. LaBar and Phelps 1997) employed words which differed in emotional meaning (positive vs. negative) but which did not elicit differences in physiological response 'between meanings'. It is possible therefore that semantic cohesion results in a greater degree of 'distinctiveness' perhaps, or cohesion may contribute to recall superiority through the effects of within-category priming (e.g. items relating to one

body part may cue another body part). The current study reduced the possibility of within-category priming by using a greater number of to be remembered items than original paired associate studies. The current study also matched neutral and emotional words for length and frequency of occurrence in written and spoken English. Nevertheless, matching for frequency does not eliminate possible effects of within-category priming. Future studies could employ additional matching procedures for the neutral words by means of artificially creating semantic categories similar to those inherent in taboo word classes. One such example is the construction of slang words to denote neutral body parts in order to control for the potential within-category priming effects of the class of taboo slang words relating to body parts.

2.4.5.3. GSR recording

Finally a cautionary note should be made concerning the conclusions to be drawn from this study concerning the effects on memory of stimulus-elicited arousal. GSR recording is notoriously 'noisy', the mean change from baseline GSR response employed in this study was recorded at the time of stimulus presentation and gives an indication of physiological arousal at the time of stimulus presentation. Each subject's mean GSR response was recorded following stimulus onset until stimulus end (GSR response latency tends to vary between 1 and 4 seconds following stimulus onset – Hugdahl, 1995). Therefore, averaging responses across trials was the norm for all participants. The accepted measurement parameter of

peak response was used. Although obvious external variables were minimised (e.g. noise) any that did occur during stimulus presentation were marked and contributed to the exclusion of a GSR response from later analysis. Nevertheless, a number of other variables other than the words themselves may have influenced the GSR response to words. For example, it is possible that naming colours used as filler items between words served to produce anxiety reflected in the GSR recording for some participants. It is unlikely that an explanation based on subject arousal to other cues and not the word presentation could explain the consistent pattern of higher responses to words classified as taboo and lower responses to items classified as neutral. However, there were large standard deviations implying marked individual differences. Some participants produced very low GSR responses and other participants, high GSR responses to a word chosen to elicit high GSR responses (see Figure 2.5.).

2.4.6. Concluding remarks

This study can be considered a more appropriate test of hypotheses relating to the incubation in memory for emotional material than studies employing paired associate paradigms with relatively few to-be –remembered items.

a) In the first instance, the present study was larger than the Kleinsmith and Kaplan study (1963) in terms of stimulus number (40 versus 9) and it assessed word recall rather than the recall of numbers associated with words. It was a within-

subject design and therefore more appropriately designed to test hypotheses relating to within-subject memory changes over time.

b) The present study represented an improvement over the LaBar and Phelps (1998) study in that better control was exerted over the words (frequency, length etc) and the pattern of memory change over time was assessed in more detail (by an assessment of memory over more recall intervals).

To conclude, employing three different methods of classifying words as 'emotional' or 'neutral' we found no evidence to support theories that suggest that emotional arousal results in incubation of material in memory over time. Rather we observed a) better memory for words subjectively rated as being emotionally arousing versus neutral. b) no evidence of incubation of material in memory over time, rather we observed the normative decay in memory over a one-week period for emotional material.

Chapter Three.

Memory for emotional material in man: the effects of noradrenaline re-uptake inhibition.

3.1. Introduction

3.1.1. The memory modulating effects of stress hormones in animals

A wealth of animal literature implicates the neurobiological processes involved in the response to stress in memory modulation for emotional events (McGaugh, 1993). The adrenergic stress hormone system is one of a number of neurobiological systems believed to be involved in this process. The animal evidence suggests that similar processes exist in humans whereby the hormonal and neurotransmitter response to stress may either enhance or impair memory for stimuli that either (a) elicit the stress response or (b) that occur at the time of the stress response. Experimental memory modulations with animals are believed to mirror the way normal modulation of human memory might occur. The emotional experience is represented by a training event (e.g. avoidance training where an animal must

learn to move position to avoid a shock). The subsequent endogenous hormone release is represented by an exogenous drug or hormone injection. Subsequent memory performance is represented by tests of retention of the training event following certain intervals. Studies have found that post training injections of hormones and/or neurotransmitters that are released during and immediately after the stressful stimulation typically modulate retention of the training event when tested at different intervals (McGaugh, 1993). For example, low doses of the stress hormone adrenaline injected post training typically enhance the retention of tasks such as Y maze discrimination (Introini-Collison & McGaugh, 1986) and inhibitory (passive) avoidance (Gold & van Buskirk, 1975). These effects are seen with delays between training and test of up to one month (Introini-Collison & McGaugh, 1986).

It seems that the effects of arousal-induced peripheral adrenaline release on memory cannot be due to the direct effects of the stress hormone at sites in the brain, because adrenaline passes the blood brain barrier poorly (Weil-Malherberg et al. 1959). The effects of adrenaline appear to be mediated by peripheral B-adrenergic receptors (Introini-Collison, et al., 1992) located on vagal afferents that project to the brain stem (Williams & Jensen, 1991). It is thought that peripheral B-adrenergic activity is involved in the activation of a central noradrenergic system, which critically involves the amygdala. Evidence indicates that aversive stimulation corresponds closely with the release of noradrenaline (NA) within the amygdala of rats as measured via implanted canula (Galvez et al., 1996). Systemic injections of adrenaline are found to induce the release of brain NA in other studies

(Gold and van Buskirk 1978a, 1978b). If the effect on memory of adrenaline is due, in part, to the release of NA within the amygdala, drugs that block noradrenaline, injected into the amygdala should also block the memory enhancing effects of adrenaline. This has been demonstrated with the beta-adrenergic blocker propranolol (Liang, Juler & McGaugh, 1986). Intra-amygdala administrations of propranolol following inhibitory avoidance training, was found to decrease the memory enhancing effect of adrenaline. Also, retention of training on the same task is enhanced by intra amygdala injections of noradrenaline and clenbuterol (a beta-adrenergic agonist) (Introini-Collison, Miyazaki, & McGaugh, 1991). The picture emerging from the research with animals has been summarized in a model of the interactions of hormones and neurotransmitter systems in regulating memory storage for emotional events (see McGaugh 2000). The model suggests that following an emotional stimulus, the body releases stress hormones such as adrenaline (from the adrenal medulla), which activate a central noradrenergic system that projects to the amygdala. The amygdala is activated and influences the storage of the specifically emotional memories in other brain regions involved in memory. According to such models the amygdala, activated by a central noradrenergic system, has a time-limited role in modulating the storage of arousal-mediated memory.

3.1.2. Noradrenaline and memory for emotional material in humans.

Studies of human explicit memory for emotional material during pharmacological manipulations are needed to fully determine the degree to which the animal findings apply to human memory. The neurobiological mechanisms

involved in human memory for emotional material remain relatively poorly understood. Cahill (Cahill et al., 1994) reported that blocking the adrenergic system in humans using the β-adrenergic blocker propranolol resulted in impaired memory for an emotional 11-slide story presentation. The slide show presentation concerns a boy who leaves home with his mother to visit his father. The story is described in three phases; the first is neutral with emotional material introduced in the second phase and relatively neutral material in the third phase. On their way, the boy is involved in a serious car accident and is rushed to a nearby hospital where his legs, severed in the accident, have to be surgically reattached. Participants viewing the slide series do so under what are essentially false pretences. They are told that the slide presentation is being used to study arousal. They are not told that the real focus of the study is memory until they return 7 days later, when they perform 'surprise' free-recall and multiple choice recognition memory tests for the slides presented. Normal healthy controls show a peak in memory performance for the second, middle phase of the story when the emotional components are introduced (Cahill et al., 1994; Cahill et al., 1995; van Stegeren et al., 1998; O'Carroll et al., 1999a; O'Carroll et al., 1999b). This phase includes a slide of the boy's reattached feet on an operating table. In the original Cahill et al (1994) study, half of the original propranolol treated participants viewed the slides accompanied with a non-emotional narrative, and these participants (unlike the propranolol participants who viewed the emotional version of the narrative) did not show impaired memory. The effects could not be attributed to effects on attention, sedative effects or emotional reactions because there was no difference in terms of subjective ratings when the propranolol and placebo participants were compared. It therefore appeared that

blocking the adrenergic system had a direct effect on subsequent memory for emotional but not neutral material. However, other studies have failed to replicate the propranolol effect on emotional memory functioning (e.g. O'Carroll et al., 1999a).

Further evidence has implicated the noradrenergic system in emotional memory (O'Carroll, 1999b). Using the same stimulus set with participants randomly allocated to beta-blockade (using metoprolol) or noradrenergic stimulation (using yohimbine), O'Carroll et al (1999b) demonstrated that yohimbine enhanced and metoprolol impaired both free-recall and recognition memory for the emotional version of the 11-slide story, relative to placebo.

3.1.3. Experimental hypothesis for the present study: Selective noradrenaline re-uptake inhibition.

Stimulation of the central noradrenergic system using yohimbine (O'Carroll et al 1999b) resulted in participants recalling and recognizing more of the emotional material after a 7-day interval compared to placebo. However, yohimbine lacks specificity and is known to affect other neuromodulatory systems such as 5HT and dopamine, as well as the adrenergic system (Den Boer and Westenberg, 1993).

The present study aimed to test the hypothesis that noradrenaline is specifically involved in enhanced memory for emotional material in man by using a new highly selective, noradrenaline reuptake inhibitor. We predicted that specifically increasing central noradrenergic activity during encoding would result in enhanced recall and recognition memory scores for the emotionally arousing

material in a dose dependent manner, relative to placebo. Selectively manipulating central noradrenergic activity was achieved using the new and selective noradrenaline re-uptake inhibitor, reboxetine ('Edronax' – Pharmacia and Upjohn) developed for clinical use as an antidepressant (Hindmarch 1997).

3.2. Method

3.2.1. Participants

The sample size for this study was chosen on the basis of sample sizes employed in previous published research on the effects on memory of pharmacological manipulations of the adrenergic system in man (O'Carroll et al., 1999a & b). In addition a large effect size was predicted in the current study and power analysis indicated that, with an effect size of .70 (Alpha = .05, power = .95) 36 participants in total (12 in each of three groups) would be required to correctly reject a null hypotheses (Faul & Erdfelder, 1992). Accordingly, thirty-six healthy young adults were recruited from the Universities of Edinburgh and Stirling in Scotland. Potential participants were required to read and sign informed consent sheets approved by the appropriate ethics committee, and answer health screening questions over the telephone. In addition, participants were warned not to undertake demanding tasks (like exams) in the days immediately following the procedure. Potential participants with a history of psychiatric illness, cardiovascular disease or abnormal blood pressure were excluded from the study, as were pregnant females.

Participants were randomly allocated to one of three groups, placebo, 4mg reboxetine or 8mg reboxetine. These doses were considered to represent an appropriate range of strengths to test hypotheses relating to memory functioning. Four mg was considered a relatively low dose because it is half the recommended initial daily dose. 8mg is the recommended daily dose (4mg b.i.d), which can be increased to 10 mg a day in the case of incomplete clinical response. Therefore, while the dose regimen in this study represented the range of doses prescribed in depressive illness, we did not employ a dose higher than the recommended daily dose.

3.2.2. Reboxetine

Reboxetine is a selective inhibitor of noradrenaline reuptake. Reuptake inhibition results in the increase of noradrenaline availability in the synaptic cleft and modification of noradrenergic transmission. Reboxetine has no significant affinity for adrenergic alpha-1, alpha-2, beta, or muscarinic receptors. No cognitive or psychomotor impairments have been observed with reboxetine in clinical studies (Kerr 1996), or in studies with healthy adults (Herman & Fuder, 1998).

3.2.3. Procedure

On arrival, participants underwent a physical examination and females were given a pregnancy test. Baseline pulse and blood pressure measurements were then taken using both Dynamap Automated Blood Pressure Monitor (Critikon,

Crowthorne, Berkshire) – (Dynamap) and the Ohmeda Finapress blood pressure recording system (BOC Healthcare, Hatfield, Hertfordshire) – (Finapress). Participants completed the Stress Arousal Checklist (Mackay et al., 1978), which yields separate scores for stress and arousal for the time the measure was completed. In a double blind procedure, participants were then given a single capsule containing 4mg reboxetine, 8mg reboxetine or placebo. The pharmacokinetics of reboxetine are such that peak serum concentrations occur 2 hours after drug administration (Dostert et al., 1997). Accordingly, all participants received their capsules 2 hours prior to slide presentation. Following drug administration, participants completed the National Adult Reading Test (NART) (Nelson & Willison, 1991) in order to estimate their intelligence and the Eysenck Personality Questionnaire – Revised (EPQ) (Eysenck et al., 1985). Participants were then provided with a choice of water, decaffeinated tea or coffee and required to sit quietly for the remainder of the 2-hour drug absorption period.

3.2.3.1. Emotional stimuli: Slide/story presentation.

The slide stimuli employed in this study were similar to the material employed by Cahill and colleagues (Cahill, 1994) but differed in that only the 'emotional' narrative presentation was used. This protocol was identical to that employed by O'Carroll et al 1999(a), 1999(b). Following the two-hour drug absorption period, participants were seated in a comfortable chair in a darkened, sound proofed booth while a series of 11 slides were projected for 20 seconds per

slide, onto a white screen (6ft by 4ft) eight feet from them. A short audio taped narration accompanied each slide (see Appendix 2 for this narrative).

For the purposes of analysis, the slide narrative presentation can be divided into the three phases. The first phase contains essentially emotionally neutral information relating to the protagonists, to the mother and son leaving home to visit the father and their journey. Emotionally arousing information is introduced in the second phase concerning the car accident, the hospital and the subsequent surgery and the third final phase deals with the aftermath of these events (the alternative arrangements that have to be made by the mother to collect her other child). During stimulus presentation, peripheral pulse and blood pressure were monitored using a Finapress finger plesthysmograph. Systolic, diastolic and pulse readings were taken following the narrated section of each slide presentation. In addition the electrocardiogram (ECG) was continuously recorded throughout the presentation, using the Biopac Student Lab Pro system (Biopac Systems Inc., Linton Instrumentation, Norfolk) connected to an Apple Macintosh 5300CS-laptop computer. Mean heart rate and standard deviation for each 20s slide/narrative presentation was calculated after data acquisition for each slide. Immediately following the completion of the slide/narrative presentation, participants were required to indicate how emotionally arousing they found the presentation by placing a mark on a visual analogue scale ranging from 1 (not at all emotional) to 10 (very emotional). Participants then completed the Stress Arousal checklist for a second time indicating their 'feelings and mood' at that particular time. Participants then had their pulse and blood pressure recorded again using both Finapress and Dynamap apparatus.

3.2.3.2. Second session - 7-day interval: Memory assessments.

One week following the initial session participants returned for a final session. Participants were told that this final session would involve administration of a further series of 'pencil and paper' type assessments similar to those carried out in the first session and that the session was required to reduce the 'workload' in the first session. On arrival, participants had their general memory assessed using the California Verbal Learning Test (Delis, 1987). This assessment has both short delay and long delay recall and recognition items. The long delay tests are administered with 20 minutes between presentation and test. The long delay recall and recognition items were administered following a test of recall and recognition of the slide/narrative series. The test of recall for the slide narrative series involved participants being asked to freely recall as many of the slides as possible from the presentation one-week earlier. They were asked to describe them in as much detail as possible and were prompted to recall both the story line as well as particular details, ('colour of clothing' and the 'direction that people were walking' were given as examples of the kinds of details participants might try and recall). Participants were told to take as long as they needed and following a response of 'that is all I can remember' were reminded that they had seen a total of 11 slides. The participants were then asked to repeat the free-recall exercise so that the experimenter could "assess which of those 11 slides you have any memory of seeing". Participants were asked to move through as many of the eleven as they could remember, describing each in detail.

Following the free-recall memory assessment, the participants were required to verbally respond to a series of multiple choice memory questions designed to assess recognition memory (these are described in O'Carroll et al., 1999b and provided in Appendix 3).

At the end of the second session, participants were debriefed and asked if they had guessed that their memory for the slide/narrative series would be assessed. None indicated that they had.

3.2.4. Statistical analysis

Between-group differences on potential confounding variables and total recall and recognition scores between the three experimental groups were analyzed using one-way ANOVA and chi-square statistics. We predicted no significant differences would be evident on potentially confounding variables, but that participants receiving 8mg reboxetine would score higher on measures of free-recall and recognition for the slide narrative presentation than participants receiving 4mg reboxetine. In turn, participants receiving 4mg reboxetine would produce higher scores on the memory measures than participants receiving placebo. Recall and recognition memory scores were also analyzed for the three distinct phases of the slide narrative series using repeated measures ANOVA (within subject factor = story phase. Between subject factor = drug group) (post hoc LSD).

In all the experimental chapters of this thesis, if any within-participants variable had more than two levels, Mauchly's test of Sphericity was conducted on the within-subject variable. The significance of Mauchly's 'W' indicates that the assumption of equivalent correlations between the variables in the ANOVA is not

supported. In the event of this analysis being significant, and according to current convention (Brace et al., 2000), a multivariate criterion of Wilks' Lambda was adopted for the within-subject factor in the analysis. In the event of this analysis being non-significant, then the univariate results would be reported.

3.2.5. Hypotheses

We expected significant effects of group (8mg > 4mg > Pl.), phase (Phase 2 emotional > phase 1, 3) and significant group by phase interactions such that 8mg and 4mg drug groups would show increased recall and recognition memory performance for the central emotionally arousing phase of the story compared to placebo. This is because enhanced central noradrenergic activity would act to amplify the 'normal' peak for the emotional material in phase 2. In addition to analysis of the differences between and within-groups, we predicted an ordered effect in total recall and recognition data such that 8mg > 4mg > placebo. This predicted ordered effect was tested using the Jonckheere non-parametric trend test (Coolican, 1994)

3.3. Results

3.3.1. Physiological and subjective responses

Participants in the three experimental groups were well matched on potentially confounding variables; no significant differences emerged between-groups for age, sex, general memory functioning (CVLT), personality function (EPQ), baseline pulse and self-ratings of stress and arousal taken at the beginning of the first session (see Table 3.1).

Table 3.1. Comparison of the three subject groups on potential confounding variables. Mean (SD)

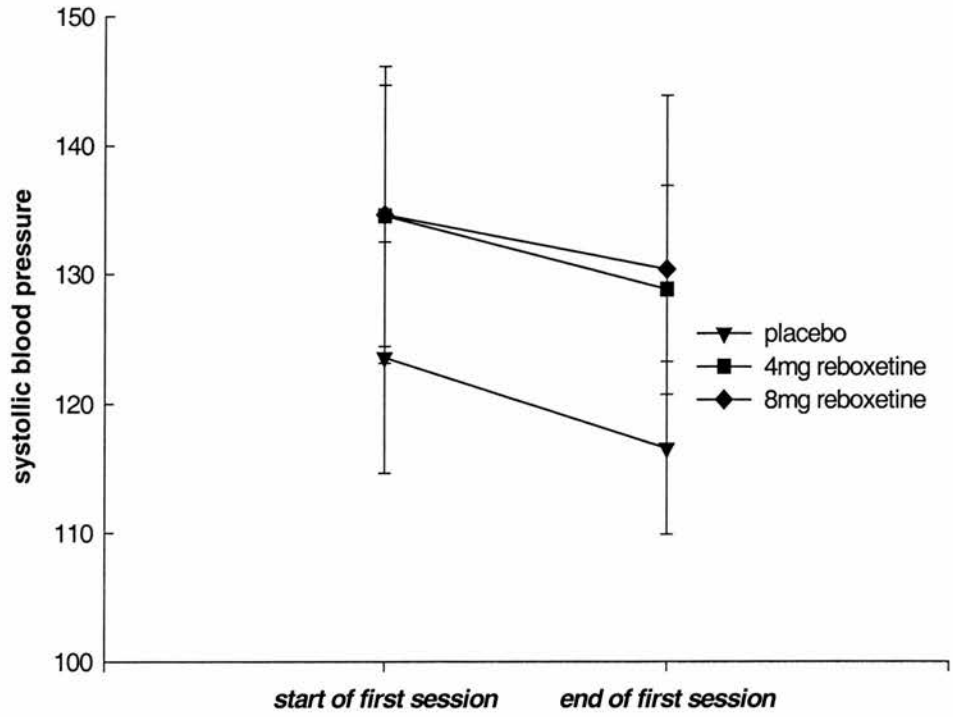
	Placebo	4mg reboxetine	8mg reboxetine	F [2, 35]	p
Age	19.83 (2.98)	19.09 (.94)	21.91 (4.55)	**1.99**	**.153**
Sex	6M, 6F	10M, 2F	10M, 2F	χ^2=**4.42**	**.109**
Baseline systolic bp.	123.58 (8.93)	134.55 (10.13)	134.64 (11.50)	**5.09**	**.012***
Baseline diastolic bp.	69.42 (4.78)	69.09 (23.14)	73.18 (7.31)	**.504**	**.609**
Baseline pulse	67.58 (13.73)	74.64 (11.56)	67.36 (17.51)	**.976**	**.387**
Baseline stress checklist	2.58 (2.57)	3.36 (4.08)	2.91 (3.30)	**.365**	**.600**
Baseline arousal checklist	6.17 (3.38)	5.45 (3.24)	7.09 (3.65)	**.057**	**.944**
CVLT A1-5	62.92 (7.90)	59.09 (7.01)	55.82 (17.36)	**1.01**	**.376**
CVLT B	7.92 (2.31)	7.27 (1.27)	8.09 (1.38)	**.746**	**.482**
CVLT SDFR	13.75 (2.42)	12.55 (2.02)	12.55 (1.92)	**.965**	**.392**
CVLT SDCR	13.58 (1.78)	13.55 (1.69)	13.09 (1.97)	**.270**	**.765**
CVLT LDFR	14.00 (2.22)	13.09 (2.21)	13.09 (2.27)	**.528**	**.595**
CVLT LDCR	14.33 (1.67)	13.45 (1.92)	13.82 (2.04)	**.519**	**.600**
N	11.42 (4.64)	11.27 (4.17)	10.55 (4.03)	**.017**	**.983**
E	16.50 (2.11)	13.64 (5.94)	14.00 (4.77)	**1.56**	**.224**
P	4.42 (3.32)	5.55 (3.33)	4.73 (3.52)	**.272**	**.764**
L	3.25 (2.56)	4.18 (5.02)	3.64 (2.16)	**.162**	**.851**
NART error	17.67 (4.42)	16.09 (4.50)	17.55 (5.41)	**.370**	**.694**

bp: Blood pressure. **CVLT**: California Verbal Learning Test – **A1-5**: total recall over first 5 presentations of 16 item word list. **B**: distracter word list. **SDFR**: Short delay free-recall. **SDCR**: Short delay cued recall. **LDFR**: Long delay free-recall. **LDCR**: Long delay cued recall. **N**: Eysenck Personality Questionnaire (EPQ) Neuroticism score. **E**: EPQ Extroversion score. **P**: EPQ Psychoticism score. **L**: EPQ Lie score. **NART**: National Adult Reading Test.

However, there were significant differences between-groups on baseline systolic blood pressure measured with Dynamap apparatus on arrival at the first session. Participants who later received either 4mg or 8mg reboxetine had slightly higher baseline Dynamap systolic blood pressure than did participants who later received placebo. Subsequent analysis indicated however, that there was no significant correlation between initial baseline systolic blood pressure and subsequent memory scores for the slide/narrative series. Therefore, participants' blood pressure was not used as a covariate. Immediately following the slide/narrative presentation, there were no significant between-group differences in subjective emotional reactions to the slide narrative series recorded using the 0-10 visual analogue scale (Cahill, 1994) [placebo = 4.67 (2.3), 4mg reboxetine = 3.91 (1.89), 8mg reboxetine = 4.82 (1.76), $F(2, 35) = .29$, $p = .75$]. There were no effects of, or interactions between group (4mg, 8mg, placebo) and time (beginning and end of first session) on either stress or arousal checklist scores [Placebo beginning: 2.58 (2.57), Placebo end: 3.0 (3.84). 4mg reboxetine beginning: 3.08 (4.01), 4mg reboxetine end: 4.17 (3.95). 8mg reboxetine beginning: 3.92 (4.70), 8mg reboxetine end: 3.42 (3.99)]. There was an effect of group [(4mg, 8mg, placebo), $F(2, 32) = 8.19$, $p = .001$], and an effect of time [(beginning and end of first session), $F(1, 32) = 14.1$, $p = .001$], on systolic blood pressure as measured with Dynamap, but no group by time interaction [$P(2, 32) = .17$, $F = .85$] (see Figure 3.1). There was a reduction in systolic blood pressure for all groups. In addition, groups receiving 8mg and 4mg of reboxetine consistently demonstrated significantly higher systolic blood pressure when measured at the beginning (Post Hoc LSD: 8mg > Pl.

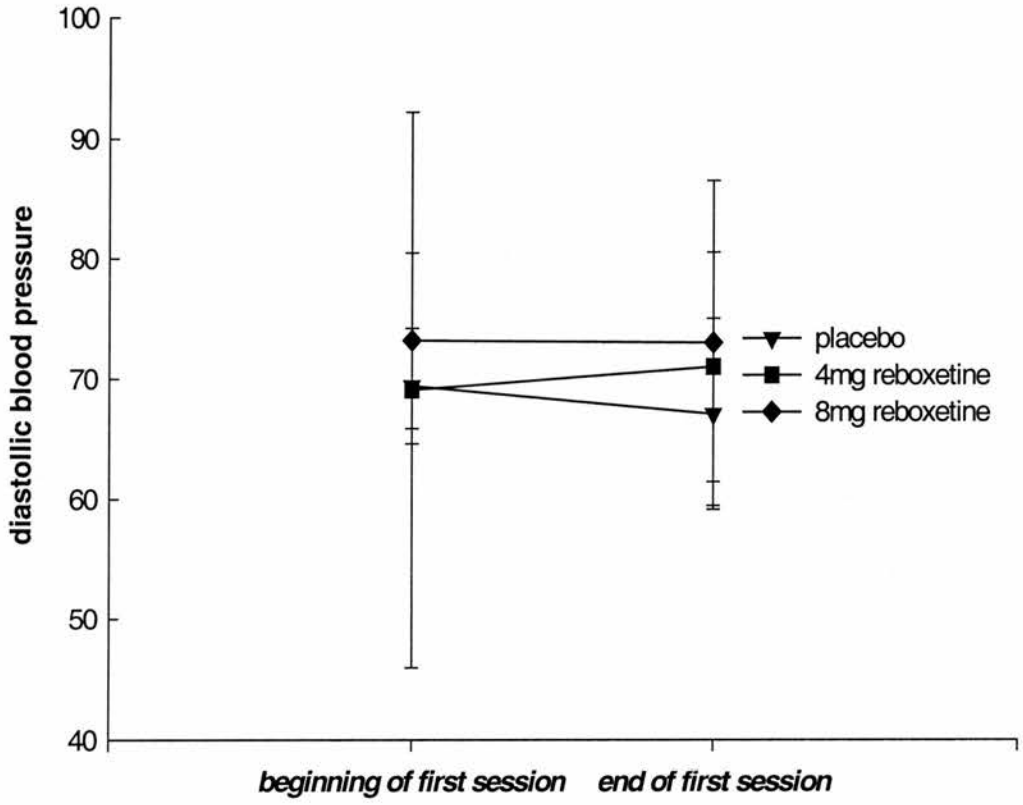
p=.01. 4mg > Pl. p=.01) and end of the procedure (8mg > Pl. p=.01, 4mg > Pl. p=.01). However, there were no effects of group [F (2, 32) = 1.24, p = .30] or time [F (1, 32) = .05, p = .83] and no group by time interaction [F (2, 32) = .26, p = .78] on measures of diastolic blood pressure measured with the same Dynamap apparatus (see Figure 3.2). There was an effect of time [F (1, 31)= 8.29, p = .01], no effect of group [F (2, 31) = 1.34, p = .23] and no group by time interaction [F (2, 31) = 2.67, p = .09] on measures of pulse as measured by the Dynamap apparatus (Figure 3.3.). Inspection of figure 3.3 reveals however that placebo and 4mg treated participants showed a drop in pulse, whereas those receiving 8mg reboxetine showed a slight increase.

Figure 3.1. The effects of Noradrenaline re-uptake inhibition on systolic blood pressure (dynamap).



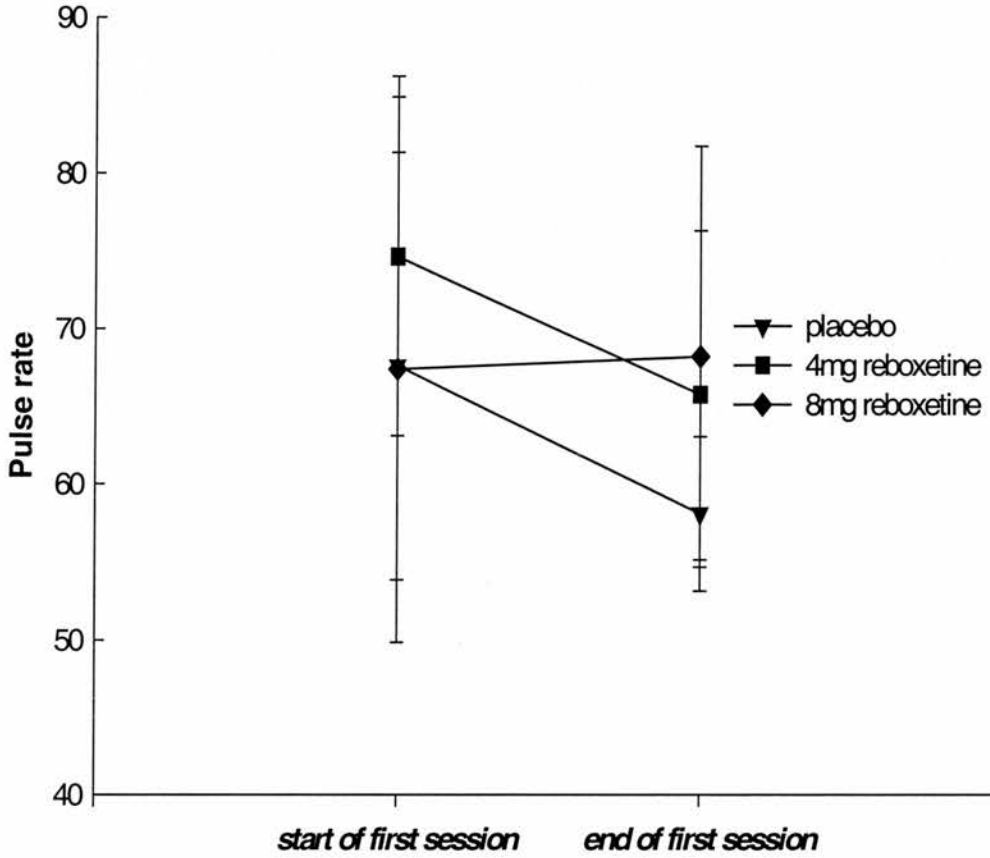
[Significant effects of group and time]

Figure 3.2. The effects of Noradrenaline re-uptake inhibition on diastolic blood pressure (dynamap).



[No significant effects]

Figure 3.3. The effects of Noradrenaline re-uptake inhibition on pulse rate (dynamap).



[Significant effect of time only]

During the slide/narrative presentation each subject had continuous ECG recordings taken using the Biopac acquisition unit. At the end of the slide presentation mean heart rate was calculated for each 20-second slide presentation. Mean heart rate was derived from the R-R wave peaks of the trace, as was the variation of the R-R interval, expressed as the standard deviation. Table 3.2 shows heart rate (with standard deviation) for each story 'phase' and for each group. The within-group variable of story phase had 3 levels. Accordingly, Mauchly's test of Sphericity was conducted and was not significant for the within-group variable of story phase [W (2) = .88, p = .16]. There was a significant effect of group on continuously measured heart rate (see Table 3.2.). Groups receiving 8mg and 4mg of reboxetine had significantly higher heart rates during the slide presentation compared to participants receiving placebo (Post Hoc LSD: (Phase 1) 8mg > Pl. p = .006. 4mg > Pl. p = .02 (Phase 2) 8mg > Pl. p = .002. 4mg > Pl. p = .015 (Phase 3) 8mg > Pl. p = .003. 4mg > Pl. p = .02). However, there was no effect of story phase on heart rate and no group by story phase interaction. The differences between-groups in heart rate derived from the Biopac ECG may have been related to the significant initial baseline differences between-groups in physiological indices on arrival. There was a significant correlation between heart rate derived from the Biopac ECG and baseline systolic blood pressure (Phase 1: Pearson .39 p = .02. Phase 2: Pearson .38 p = .03. Phase 3: Pearson .39 p = .03). When baseline systolic blood pressure, measured by Dinamap, was entered in the heart rate analysis as a covariate, the heart rate group effect was reduced (F (1, 28) = 2.99, P = .07). There was no significant effect of story phase on heart rate variability as measured via the standard deviation of the R-R interval of the ECG (see Table 3.2). For the analysis

of standard deviation of heart rate, Mauchly's test of Sphericity was significant for the within-group variable of story phase [W (2) = .11, p = .01] and therefore, the multivariate criterion of Wilks' Lambda was used to test this variable and these results are reported in Table 3.2.

To summarize the subjective and psychophysiological results, initial differences in blood pressure on arrival did not correlate with memory performance in the three groups. In addition there were no significant between-group differences in subjective emotional reactions to the slide stimulus materials or subjective stress/arousal ratings taken before and after stimulus presentation. The drug groups showed evidence of heightened heart rate compared to placebo over all three phases of the presentation.

Table 3.2 Continuous measurements of heart rate by phase of slide/narrative presentation (1-3) and group (Placebo, 4mg reboxetine, 8mg reboxetine).

Placebo phase			4mg reboxetine phase			8mg reboxetine phase			**Group.** (2, 29)	**Phase.** (2, 58)	**GroupxPhase** (4, 58) (2, 28)
1	2	3	1	2	3	1	2	3			
Rate											
63.26	62.57	62.57	75.67	75.12	74.74	76.59	78.20	77.64	F = 5.98	F = .32	F = .2.28
(6.10)	(6.9)	(5.97)	(10.72)	(9.6)	(9.93)	(13.62)	(14.07)	(14.48)	P = .001*	P = .73	P = .07
SD											
4.36	3.89	4.41	4.89	3.37	10.49	5.24	4.96	4.70	F = .535	F = 2.39	F = .784
(2.53)	(2.07)	(2.09)	(4.04)	(1.46)	(21.84)	(3.05)	(2.83)	(3.14)	P = .591	P = .111	P = .466

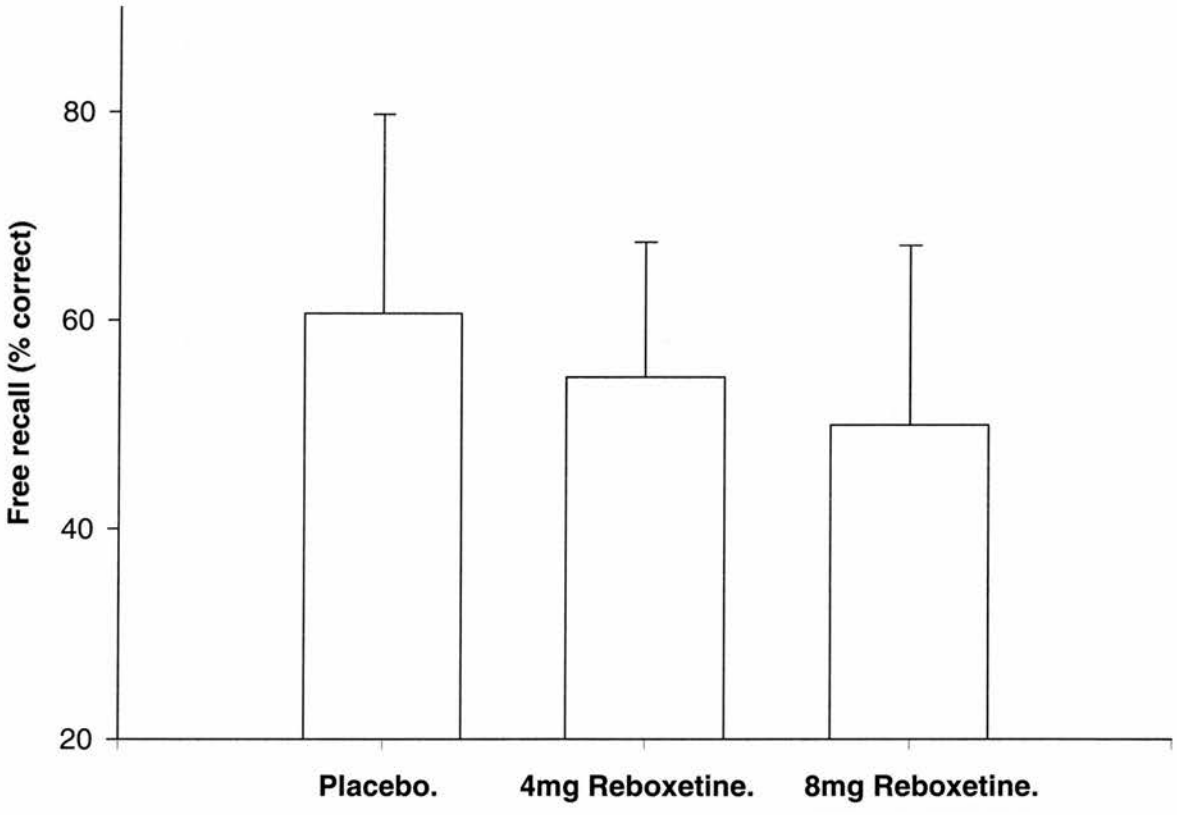
Rate (ECG): Mean heart rate (beats per minute) acquired and calculated using Biopac.

3.3.2. Effects on free-recall memory for the slide/narrative series

Following the one-week interval, participants were asked to freely recall as many of the slides as they could remember seeing in the first session seven days previously. Inspection of Figure 3.4 reveals that for total free-recall scores (% correct), participants receiving placebo recalled more slides than did participants receiving 4mg of reboxetine, and the 4mg group recalled more slides than the group receiving 8mg of reboxetine. However these between-group differences were not significant [F (2, 35) = 1.23. p = 0.30 – see Figure 3.4]. In addition the predicted trend in recall scores (i.e. that the 8mg reboxetine group would recall more slides than the 4mg group, who would recall more slides than the placebo group) was not significant (Jonckheere S = -180 p>0.05), as the observed direction of effect was opposite to that predicted. The results were then analysed by story phase (following Cahill et al., 1994; Cahill et al., 1995; O'Carroll et al., 1999a; O'Carroll et al., 1999b; van Stegeren et al., 1998). Mauchly's test of Sphericity was not significant for the within-group variable of story phase [W (5) = .95, p = .43] and therefore, univariate results are reported. Analysis of the percent correct free-recall scores revealed an effect of phase [F (2, 66) = 16.56, p = .001]. Placebo group phase 1 (mean %) = 66.67 (sd = 30.77), phase 2 = 70.83 (25.75), phase 3 = 41.67 (15.08); 4mg reboxetine group phase 1 = 60.42 (27.09), phase 2 = 64.58 (16.71), phase 3 = 33.33 (20.1); 8mg reboxetine group phase 1 = 52.08 (22.51), phase 2 = 58.33 (22.19), phase 3 = 38.88 (27.83)]. There was no group effect [F (2, 33) = 1.17, p = .32)], and no group by phase interaction [F (4, 66) = .45, p = .78]. Thus, all three groups

(placebo, 4mg and 8mg reboxetine) exhibited the normal response and freely recalled most slides from story phase two (emotive), to an equivalent degree.

Figure 3.4 Total free-recall memory scores for the slide/narrative presentation

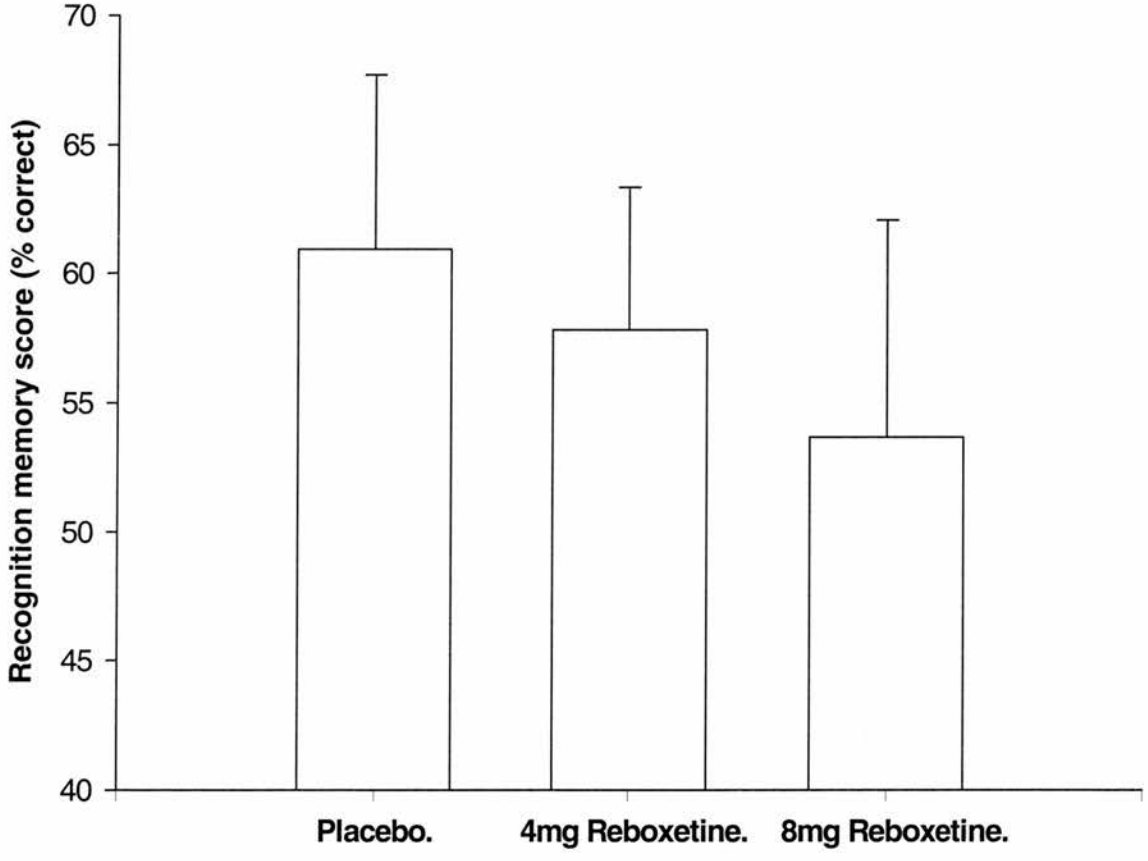


[No significant between-group differences in free recall memory]

3.3.3. Effects on recognition memory for the slide/narrative series.

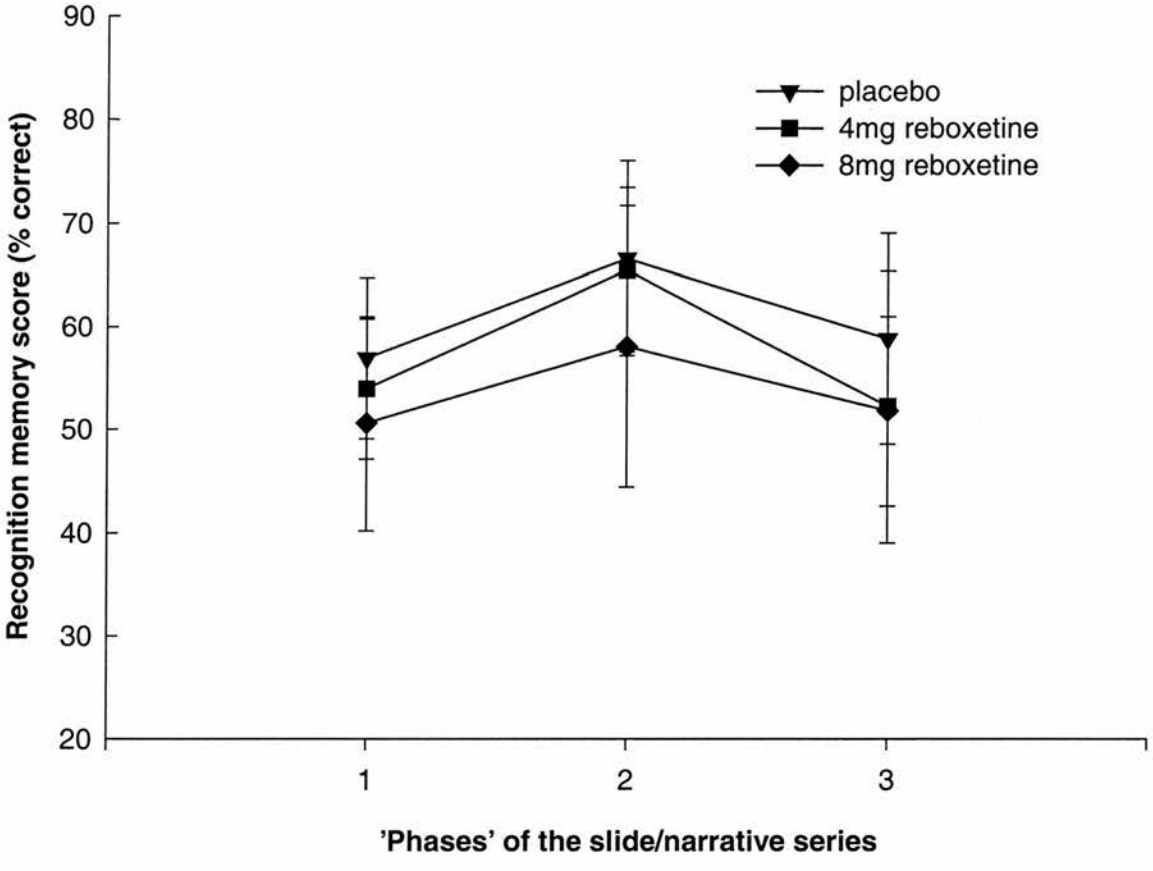
Total mean recognition memory performance as assessed using the multiple-choice questions at one-week interval is displayed in Figure 3.5. Significant between-group differences were apparent [F (2, 35) = 3.25. p = .05. Post hoc LSD: Placebo> 8mg reboxetine. p = .02]. The predicted trend in recall scores (i.e. that the 8mg reboxetine group would produce higher recognition scores than the 4mg group who would, in turn produce higher recognition scores than the placebo group) was not significant (Jonckheere S = -178 p>0.05). Supplementary analysis revealed an ordered effect, *directly opposite* to the predicted direction in total recognition scores. Thus, participants receiving placebo produced higher recognition memory scores than participants receiving 4mg reboxetine who in turn produced higher recognition memory scores than participants receiving 8mg reboxetine. Mauchly's test of Sphericity was not significant for the within-group variable of story phase [W (2) = .93, p = .36] and therefore, the univariate results are reported for this variable. All three groups showed the expected heightened total recognition scores for the second emotive phase of the presentation (Figure 3.6). There was a clear effect of story phase [F (2, 66) = 13.23, p = .01], a significant group effect [F (2, 33) = 3.26, p = .05] and no group by story phase interaction [F (4, 66) = .54, p = .71 (see Figure 3.6)].

Figure 3.5. Total recognition memory scores for the slide/narrative presentation



[Significant between-group differences in total recognition memory]

Figure 3.6 Recognition memory scores over the three phases of the slide/narrative presentation



[Significant effect of group and story phase]

3.4. Discussion

3.4.1. Summary of main findings

In the present between-subject, double blind study, random allocation to groups resulted in good matching between-groups on a number of potentially confounding variables, e.g. age, sex, baseline physiological and subjective measures of arousal, general memory functioning, personality and intelligence. The existing literature supported the prediction that noradrenaline re-uptake inhibition should result in an enhancement in emotional memory performance relative to placebo. The free-recall memory performance of participants in this study indicates no statistically significant differences between-groups receiving placebo, 4mg or 8mg of reboxetine, but with an order of placebo > 4mg > 8mg reboxetine. Recognition memory performance for the slide narrative series indicated that participants who received placebo recognized significantly *more* of the material presented than participants who received reboxetine. This pattern of memory performance is directly opposite to that predicted. The predicted pattern in both recall and recognition scores was based on a wealth of animal literature and a growing body of human evidence that strongly implicates the central noradrenergic system in the process of memory modulation for emotional material. The difference between

participants' performance on the two measures of memory, recall and recognition may possibly be explained by the greater sensitivity of the recognition memory measure used in this study. However the overall pattern of effect was similar for both recall and recognition, with placebo treated participants performing best, followed by 4mg and 8mg reboxetine treated participants performing worst.

3.4.2. The effects of subjective emotional reactions on memory performance.

The difference in memory scores between-groups cannot be explained by differences in emotional reactions to the stimulus materials. In the first instance, there was no significant difference between the groups in participants' immediate 0-10 visual analogue subjective rating of how emotional they found the presentation to be. In the second instance, no significant differences emerged when subjective stress and arousal checklist scores were compared between the groups both pre and post stimulus presentation. Taken together, these results indicate that between-group differences in subjective emotional reaction to the presentation could not, in themselves, be responsible for modulating the encoding of the stimuli because memory scores differed between-groups while subjective emotional reactions did not. All three groups showed the normative response in memory scores in that all participants, regardless of group, showed an increase in both recall and recognition memory scores for the middle, emotionally arousing, phase of the slide / narrative presentation (Figure. 3.6).

3.4.3. Can the memory effect be explained by drug sedation?

The observed differences in memory scores for recognition between placebo and drug manipulation may have been due to an indirect pharmacological effect of the drug, indeed one explanation is that the drug sedated the participants in a dose dependent manner, thus interfering with encoding. Experimenter observations of participants indicated profound sedation in three participants at the end of the first session. On breaking the drug code, it transpired however, that two of these participants had, in fact received placebo, and a third had received 4mg of reboxetine. Reboxetine is not considered to be a sedative per se, and no cognitive or psychomotor impairments have been observed with reboxetine in clinical studies (Kerr et al. 1996) or studies with healthy adults (Hindmarch, 1997). As stated above, subjective self-ratings of arousal did not differ between-groups when measured immediately following the presentation of the stimuli. The completion of the checklist at this time was approximately 10 minutes following peak plasma levels of the drug. Thus the drug manipulation did not impair subjective arousal at the time encoding of the 'to-be-remembered' stimuli took place.

Is it possible that baseline differences in physiological arousal between-groups explain the differences in subsequent memory performance? In the present study, heart rate did not change in response to the phases of the story, but heart rate was significantly higher over all three phases for the drug groups as compared to the

control participants. The implication of models of central noradrenergic activity proposed by McGaugh (1993) is that increases in central noradrenergic activity may depend upon or be triggered by the release of peripheral stress hormones that are part of the physiological response to stress. Heart rate changes are part of this physiological response. Therefore, it could be argued that, if anything, the drug groups should have evidenced better memory performance than controls (because of increased heart rate reflecting heightened noradrenergic activity/tone). However, their memory scores were consistently worse. The higher heart rate and subsequent poorer memory performance of the drug groups as compared to controls does not sit well with the results of previous studies. O'Carroll et al., (1999b) and Van Stegeren et al., (1999) reported decreased heart rate following beta blockade to be associated with poorer memory performance relative to placebo, using the same stimuli as used in the present study.

3.4.4. Anticholinergic effects: How selective is reboxetine?

It has been reported that reboxetine has no significant affinity for adrenergic alpha-1, alpha-2, beta, or muscarinic receptors (Pharmacia and Upjohn). The antagonism of such receptors is believed to be associated with the cardiovascular, anticholinergic and sedative side effects of other antidepressant drugs. Therefore, by implication, reboxetine is not a sedative *per se* and few anticholinergic side effects should be evident. It has been reported, however, that participants receiving either imipramine or reboxetine are equally likely to experience side effects such as dry mouth, constipation, sweating, and urinary hesitancy/retention (Katona et al., 1999). These side effects are usually considered to reflect anticholinergic activity. It

is clearly established that anticholinergic drugs impair memory performance (Frith, 1984). Based on this evidence, it is suggested that reboxetine, while highly selective for the noradrenergic system, may produce anticholinergic side effects which may impair cognitive functioning. No cognitive or psychomotor impairments have been observed with reboxetine in some clinical studies (Kerr et al. 1996) or in studies of healthy participants (Herman & Fuder, 1998). However these studies have not used doses exceeding 4mg. More evidence is required concerning the effects on cognitive functioning in healthy adults of doses equivalent to the recommended daily dose for adults suffering from depressive illness (4 mg b.i.d – 8mg/day), i.e. the doses used in the present study.

3.4.5. The U-shaped curve: Was the dose regimen appropriate?

The animal literature implicates the adrenergic system in arousal-mediated memory in a dose-dependent way, lower doses enhance and, typically, higher doses impair memory (Introini-Collison & McGaugh, 1986). It is possible therefore that both 4mg and 8mg of a NARI, reboxetine may represent relatively high doses in studies of human memory for emotional material. One possibility would be to replicate this study using the lower doses that have been used in studies, which have tested the effects of reboxetine on non-emotional cognitive and psychomotor performance (Kerr et al., 1996). A study comparing memory performance for the same slide stimulus materials using placebo, 0.5mg, 1mg and 4mg doses could help

clarify questions relating to dose dependency. It is possible that memory enhancing effects may be demonstrated with lower doses of reboxetine.

3.4.6. Source of arousal

Another way of viewing the present results is to suggest that the *source* of arousal is critical in memory for emotional material – i.e., the emotional material itself must elicit an arousal reaction of some kind for the stimulus to be well remembered. Recent studies have persuasively demonstrated that memory for the slide material used in this study does not benefit from 'free floating' physiological arousal. Libkuman and colleagues (1999) found that stationary cycling or running did not increase subsequent memory performance for the slide stimuli when compared to sitting still. Subjective emotional arousal, not physiological arousal appears to determine an event's memorability (see Chapter 2). The placebo group in the present study, showed no change in physiological indices of heart rate or systolic blood pressure during the presentation of the stimulus materials, and rated them on the visual analogue scale, on average, at 4.7 /10 (sd 2.3). It is possible to argue that the stimulus materials, although containing emotional material, were not seen as particularly emotionally arousing by the participants in this study (however, the ratings obtained in this study are similar to those obtained by O'Carroll et al., 1999(a) & (b) and by Cahill et al., 1994 and van Stegeren et al., 1998). Nevertheless the groups showed the normative pattern of enhanced recall and recognition scores

for the emotional central phase of the story 1-week later and an apparent dose dependent memory impairment.

3.4.7. Selectivity of the noradrenergic system for arousal mediated memory.

Our results suggest that, administering 4- and 8mg of reboxetine to healthy adults impairs memory for the emotional slide / story. However, participants in all groups demonstrated the normative pattern of enhanced memory for the middle, emotional phase of the presentation when the emotional elements of the story are introduced. No significant group by phase interactions were observed in this study on any of the measures of memory administered. In addition, between-group differences tended to be significant across all three story phases (both emotional and neutral). It is difficult therefore to claim the memory impairing effects of reboxetine were specific to the emotional elements of the story, but rather seemed to have a general effect on both neutral and emotional phases. A useful replication of this study could utilize both the emotional and neutral narratives accompanying the slide stimulus materials (see Cahill et al 1994). If the noradrenergic system is critical in memory for specifically emotional events, selective noradrenergic re-uptake inhibition should affect memory for the slides accompanied by the emotional narrative, but it should not influence memory for the same slides accompanied by the neutral narrative.

3.4.8. Reboxetine and yohimbine: same mode of action, differential effects on memory?

Our results pose questions for theories that implicate increases in central noradrenergic tone as critical in the formation of memory for emotional material. Studies published to date have demonstrated the memory enhancing effects of stimulation and the impairing effect of blockade of this system. How can the results of the present study be reconciled with the results of previous studies? Few studies have looked at the effects of stimulating the central noradrenergic system in man. O'Carroll and colleagues (1999b) found that 20 mg yohimbine hydrochloride increased recall and recognition scores for the slide presentation used in the study reported here relative to placebo (while blockade, using 50mg metoprolol impaired memory relative to placebo). Yohimbine hydrochloride acts to increase central noradrenergic activity via blockade of the alpha-2 adrenergic autoreceptor (Charney et al., 1987; Peskind et al., 1995). It is difficult to reconcile the opposing memory performance displayed by participants viewing the same stimulus material, in the same laboratory, but receiving either yohimbine (O'Carroll et al., 1999b) or reboxetine (present study). One would expect to see similarities in memory scores in the two studies if noradrenaline is critically involved in memory for emotional material. Both yohimbine and reboxetine treated participants showed an increase in heart rate compared to placebo, but opposing patterns of memory performance. One possibility is that yohimbine is less selective than reboxetine and has effects on other neurotransmitter systems in addition to the noradrenergic system, (e.g. 5HT & dopamine – Den Boer & Westenberg, 1993) that may, in themselves, be influential

in the processes involved in enhanced memory for emotional material. Other neurotransmitter systems and processes are known to be implicated in memory modulation for emotional events. These include a number of different stress hormones including the opioid peptidergic and GABAergic systems (McGaugh 1993) and the hypothalamo-pituitary-adrenal axis (Yehuda and Harvey, 1997).

3.4.9. Summary and Conclusions

A wealth of animal literature and a growing body of human evidence implicate the central noradrenergic system in the process of memory modulation for emotional material. Notably, evidence indicates that blockade of the beta-adrenergic system in humans results in decreased recall and recognition memory performance, relative to placebo for the emotional elements of a series of slides accompanied by a narrative. Stimulation of this system with yohimbine has resulted in increased recall and recognition performance relative to placebo for the same stimulus materials.

The study reported here was the first study of emotional memory to have manipulated the central noradrenergic system using 4mg and 8mg doses of the selective noradrenaline re-uptake inhibitor, reboxetine, in a double blind, randomized between-group, placebo controlled design with 36 healthy adults. We hypothesized that noradrenergic re-uptake inhibition would result in a dose dependent increase in free-recall and recognition memory performance, relative to placebo for the same slide stimulus materials. However, we found a dose dependent

effect on recall and recognition scores *opposite* to the predicted direction (placebo> 4mg>8mg) and no significant differences between-groups in self-rated stress and arousal scores or self-rated emotional reactions to the stimuli. These results may be interpreted as raising questions for theories that propose an intimate link between circulating central noradrenaline levels and memory for emotional material. The study also raises questions concerning the selectivity for the noradrenergic system of reboxetine.

Chapter Four

Alexithymia and memory for emotional material

4.1. Introduction.

4.1.1. Alexithymia

The term 'alexithymia' was initially used by Sifeneos (1973) to describe a style presented by certain psychosomatic general hospital patients who had been referred for psychiatric consultation. As a 'cognitive affective style', alexithymia is present in the healthy population. It is characterized by a marked inability to describe feelings, a cognitive style excessively focused on external details, and a paucity of imaginative thought, dream recall or fantasy (Taylor, 1994). For example, when asked "how would you feel if you saw a truck coming at you at 90 miles per hour?" alexithymics might respond "how would I feel? I don't know, no feeling; I'd get out of the way" (example taken from alexithymic subject number 21 – Krystal et al., 1986).

Alexithymia is also associated with a variety of chronic medical conditions like asthma (Dirks et al., 1981), hypertension (Osti et al., 1980), chronic pain syndrome (Mendelson, 1982), alcoholism and substance abuse (Rybakowski et al., 1982). As a construct, it has been measured in samples of college and university

students and community groups (Bagby et al., 1988; Parker et al, 1989). It has also been differentiated from other personality variables like neuroticism, as well as from anxiety and negative affect (Martin and Phil, 1986; Martin et al., 1986). As Wehmer and colleagues point out (1995) it poses interesting questions concerning our understanding of human emotional experience. For example, the difficulty experienced by alexithymics in describing differentiated feelings could involve a failure at the level of language, cognitive differentiation, or appraisal. The authors of the Toronto Alexithymia Scale have suggested that memory research is required with alexithymics to investigate possible differences in the ways in which high and low scorers on the alexithymia scale process emotional and non emotional material (Bagby et al., 1994). A growing body of evidence suggests that the marked inability to differentiate feelings may reflect a difference in somatic feedback to the brain also. A variety of studies have demonstrated differences in physiological responses and subjective responses to a range of stimuli in high and low alexithymics (Lane and Schwartz, 1987; Martin & Phil, 1985; Nemiah 1977; Tenhouten et al., 1988; Papciak et al., 1985; Rabavilaz, 1997; Hyer et al., 1990). However, comparatively few studies have assessed memory performance in high and low alexithymics. Alexithymia may inform our understanding of the processes by which both subjective and physiological responses influence memory functioning. It seems that intense emotional events lead to a change in physiological and subjective arousal and such events tend to be well remembered. If differences in physiological or subjective reactions to such stimuli exist in alexithymia compared to normal participants, then differences in memory performance may follow. Moreover, a

memory deficit for specifically emotional material could be expected compared to memory for neutral material, given that the apparent difficulty in alexithymia is specifically affective in nature. If physiological differences between high and low alexithymics are replicable and robust, studying the emotional memory performance of high versus low alexithymics could highlight important links between memory performance for, and physiological responses to, emotional material.

4.1.2. Psychophysiological indices of emotional responsiveness in high versus low alexithymics

4.1.2.1. De-coupling

Research on the physiological differences between high and low alexithymics has produced mixed results. One suggestion has been that the deficit in alexithymia is associated with a lack of 'normal reciprocal relationships between psychic and somatic components of the affective system' (Nemiah et al., 1977). This suggestion is based on evidence of an apparent dissociation between certain physiological indices of arousal and subjective indices of stress during a variety of tasks.

4.1.2.2. Reduced physiological reactivity in alexithymia?

Nemiah and colleagues (1977) compared psychosomatic patients who displayed alexithymic characteristics with healthy controls. They found that

alexithymic individuals showed no change in oxygen consumption compared with baseline when performing mental arithmetic tasks and when instructed to think sad, angry, happy and frightening thoughts. The arithmetic task was considered to be a stress-provoking paradigm. Normal healthy controls increased their oxygen intake over the two conditions.

4.1.2.3. Increased tonic physiological response in alexithymia?

Martin and Phil (1985) found similar evidence for a lack of reciprocity between physiological and psychological components of the stress response in alexithymia, however their results were interpreted as evidence for increased affect-related autonomic reactivity in alexithymia. They measured frontal electromyogram (EMG), digital blood volume pulse amplitude, heart rate and subjective stress ratings in high and low alexithymics in a 10-minute stress quiz. They found a significantly lower correlation between digital pulse volume amplitude and heart rate in high alexithymics, which they interpreted as evidence of higher tonic (i.e. baseline) levels of physiological arousal. They found no differences in physiological reactivity to stress on any of the physiological measures between high and low alexithymics. However, they found a lower correlation of frontal EMG and subjective stress ratings during the recovery phase in the high alexithymics following the stress quiz. They interpreted this as evidence for a 'de-coupling' of stress responses from autonomic responses in alexithymia.

4.1.2.4. Normal subjective response in alexithymia?

Papciak et al (1985) conducted further work on the relationship between the physiological response to stress in alexithymia and the subjective response to stress. They predicted that alexithymic male college students would produce the normal physiological response to stress but would be less reactive in terms of subjective self-reports (i.e. that they would also show evidence of decoupling). Like Martin & Phil (1985) they used a stress quiz paradigm to provoke autonomic responses and a profile of mood states to assess emotional responses to stress. However, Papciak et al., (1985) found no differences in reported mood-state and similar increases in EMG and heart rate between alexithymics and controls thus failing to find evidence of decoupling in alexithymia. Alexithymics did however report higher levels of tension during baseline recordings and displayed significantly higher tonic heart rate throughout the experiment. This suggests that there exist generalized lasting differences in terms of tonic physiological arousal levels between high and low alexithymics, and that the difference between highs and lows is not simply in terms of reactivity to experimental stressors.

4.1.3. Alexithymia in normal and patient groups

Studies of patient populations seem to differentiate between high and low alexithymics in terms of physiological responses more reliably than studies

involving high and low alexithymic college students. Rabavilaz (1997) exposed high and low alexithymic patients to a standard tone followed by a novel tone. The groups had been drawn from outpatients suffering form anxiety disorder, phobia and obsessional neuroses. Alexithymic patients had a higher level of spontaneous fluctuation in skin conductance, greater amplitude of response to the novel tone and a slower recovery time during the novel tone. They found no differences in anxiety self-ratings between high and low alexithymia groups. Again, 'de-coupling' was proposed to account for the fact that whereas the high alexithymia group showed no correlation between anxiety ratings and electrodermal activity, a significant correlation was evident in the low alexithymia group. Another example of significant between group differences in physiological responses to emotion provoking stimuli in patient population is a study of Vietnam veterans with Post Traumatic Stress Disorder (Hyer et al., 1990). High and low alexithymic Vietnam veterans with PTSD were read accounts of battle experiences based on information gathered in previous interviews with them. All participants reacted to the stressor. The more alexithymic the subject, the more he reacted in terms of heart rate difference between the stressor period and the baseline. Therefore, this clinical sample of high alexithymic patients showed evidence of being *more* reactive, unlike the previously reviewed studies of healthy controls.

On the basis of the evidence reviewed here, it would appear that the evidence for significant differences between physiological responses of high alexithymics compared to low is inconsistent. Evidence indicates that an undifferentiated (Papciak et al., 1985; Martin & Phil, 1985) or diminished (Wehmer et al., 1995) situational

induced physiological reaction to provoked arousal is associated with high compared to low alexithymia in healthy participants. It is important to note that many of the studies that have demonstrated increases in induced physiological responses to provocation in high alexithymics have done so with patient populations. It is reasonable to suggest that studies of PTSD veterans (Hyer et al, 1990), psychosomatic individuals (Nemiah et al., 1977), anxious, phobic and obsessional psychiatric patients (Rabavilaz, 1997) may confound the effects of alexithymia on physiological responses with the effects of the various other emotional disorders on physiological responses.

However, at least two studies with a non-clinical population (Papciak, et al., 1985; Wehmer et al., 1995) have demonstrated higher tonic or baseline heart rate in high alexithymic students compared to low alexithymic students. Importantly, the latter study employed more than one measure of alexithymia [measurement of alexithymia was via The Toronto Alexithymia Scale (Bagby et al., 1988) and a study of the number of emotion words used by participants when writing about a series of images [the 'emotion words (EW) measure - Wehmer et al., 1995]. Results indicated that when participants were defined as high on both measures of alexithymia, baseline heart rate was higher in the high alexithymia group. In addition, heart rate change from baseline when participants viewed a series of pleasant and unpleasant slides was lower in the high versus the low alexithymia group (Wehmer et al., 1995) thus, again showing *reduced* physiological reactivity in a non-clinical sample scoring high on alexithymia.

4.1.4. Can a physiological 'signature' in alexithymia predict emotional memory performance?

4.1.4.1 Subjective responses

The evidence reviewed so far would tentatively indicate that healthy normal participants producing high scores on measures of alexithymia may demonstrate higher tonic or baseline measures of autonomic activity but be less physiologically reactive to experimentally induced stress. Moreover, studies of patients and healthy adults indicate that there should be no difference in subjective response to emotionally arousing stimuli materials between high and low alexithymics. (Papciak et al 1985; Rabavilaz et al 1997)

4.1.4.2. Source of arousal

Source of arousal is critical when studying memory for emotional material – i.e., the degree to which the emotional material itself elicits an arousal reaction of some kind (subjective and/or physiological) would seem to affect the degree to which the arousal-eliciting stimulus is well remembered. Recent studies have persuasively demonstrated that memory for a series of slides depicting an emotional story (see Chapter 3.) does not benefit from 'free floating' physiological arousal that is not elicited by the to-be-remembered stimuli. Also, Libkuman and colleagues (1999) found that stationary cycling or running while viewing emotionally arousing stimuli did not increase memory performance for the slide stimuli when compared to sitting still. They interpreted their findings by suggesting that participants who were

not physiologically aroused were nevertheless subjectively emotionally aroused (they rated the story as being more emotional than a closely matched neutral story). Therefore, emotional arousal and not necessarily physiological arousal determines an event's memorability. Participants producing high and low alexithymia scores may not differ in terms of their subjective rating of emotional arousal (as evidence reviewed above would indicate). If subjective ratings do not differ then no difference in memory performance should be evident for the same slide story stimulus materials according to source of arousal theories (Libkuman et al., 1999). This is because the subjective rating of how emotionally arousing the 'to be remembered' stimulus is, does not differ between groups (despite the fact that other studies show higher tonic levels of physiological arousal in high alexithymia – e.g. Wehmer et al 1995).

4.1.4.3. Physiological reactivity

Evidence reviewed above may indicate that high scorers on the alexithymia measures may be less *physiologically* reactive (in terms of heart rate change from baseline) to an emotional stimulus compared to low scorers possibly, due to elevated basal levels. According to the argument presented in the paragraph above, *source dependent* physiological arousal response that is less pronounced in high alexithymics compared to low alexithymics may translate into poorer memory for the stimulus materials. High scorers on the alexithymia measure may therefore produce lower memory scores because the source material is producing a muted

physiological response compared to the low scorers. This prediction is based on the assumption that a *physiological response to the stimulus* determines memory performance because that physiological response indicates the degree to which the stimulus elicits arousal. However, if *self–rated emotional arousal* in response to the stimulus is more predictive of memory, then the degree to which a stimulus elicits physiological arousal should be relatively unimportant in terms of subsequent memory performance. The critical determining factor that predicts memory performance should be the self-rated emotional response to the to-be –remembered stimulus. If this study demonstrates that high alexithymics only differ in terms of physiological reactivity to stimuli from low alexithymics, then no differences in memory performance should be expected (according to studies showing that self-rated emotional reactions predict memory). However, if the self- rated emotional reaction to the stimulus predicts memory, differences in memory scores between high and low alexithymics should be evident only if they differ in their self- rated emotional reaction to the story.

4.1.5. Summary of predictions concerning memory:

1. High alexithymics will demonstrate lower physiological reactivity to emotional stimuli than low alexithymics (similar to recent findings –Wehmer et al., 1995). If physiological reactivity to stimuli predicts subsequent memory for those

stimuli, high alexithymics will therefore produce lower memory scores compared to the low alexithymics when assessed one-week later.

2. If high alexithymics show lower subjective self-ratings of emotional response then significantly lower memory scores will be evident when assessed one – week later.

4.2. Method.

4.2.1. Participants:

An a priori power analysis was conducted (F-tests on means in the ANOVA). A large effect size was chosen (F = .80, Alpha = .05, power = .95) which required a total sample size of 24 participants (12 in each of two groups) [F (1, 22) = 4.31]. The final laboratory based sample consisted of 24 female volunteers selected from a single day's attendance at three large undergraduate psychology course lectures at the University of St Andrews and a poster advertisement campaign at both academic staff and student venues at the University of St Andrews. Selection was made after potential participants had read and signed an information sheet and completed the 20-item Toronto Alexithymia Scale [TAS-20 (Taylor et al., 1997; Bagby et al., 1994) – see Appendix 4 for the TAS-20]. Of the 400 potential participants who received information sheets and TAS-20, 90 participants returned a signed sheet and completed the alexithymia questionnaire indicating that they consented to participate in the main laboratory based sessions (2 sessions in total) if selected and contacted at a later date. Two groups of participants were then formed based on responses to the

TAS-20 scale (see apparatus and materials section). Among the 90 participants 12 participants were selected who had scored in the lower quartile of the TAS-20 total score (≤ 51) and 12 participants were selected who had scored in the upper quartile. All respondents who scored in the upper quartile and the lower quartile were female. The high alexithymic group had a mean TAS-20 score of 63 (SD = 4.70) (range 54 – 69) and a mean age of 19.25 yrs (SD = 1.48) (range = 18 – 22). The low alexithymic group had a mean TAS – 20 score of 32 (SD = 2.25) (range 27 – 35) and a mean age of 19.92 (SD = 1.56) (range = 18 – 23). Of the 90 participants who returned completed TAS-20 questionnaires 8 participants produced scores in the recommended alexithymia range (≥61 – Taylor et al 1997). Four additional participants who had produced the next highest scores had to be incorporated into the high group (scores = 54, 58, 58, 59). These participants all scored above the cut off score for the non-alexithymic group (≤ 51) and the overall mean TAS-20 score for the high alexithymia group was above the high alexithymic cut off point of 61. None of the participants were told that the study aimed to assess memory but that the

"study aims to assess people's reactions to a series of pictures. The reaction we will study is one of the many involved in the sympathetic nervous system more commonly known as the fight or flight response. We would like to compare the reactions of people who score differently on certain measures of emotion."

All participants were given the option of receiving either course credit or £8 for participating in the study.

4.2.2. Apparatus and materials

4.2.2.1 Participant matching

a) Self rated stress and arousal

Participants completed the Stress Arousal Checklist (Mackay et al., 1978), which yields separate scores for stress and arousal for the time the measure was completed – see Appendix 5 for predictions, results and brief discussion relating to habituation in alexithymia. The results of baseline stress and arousal self-ratings presented in this Appendix.

b) Predicted IQ

The National Adult Reading Test (NART) (Nelson & Willison, 1991) was administered in order to estimate intelligence.

c) Personality

The Eysenck Personality Questionnaire – Revised (EPQ) (Eysenck et al., 1985) was administered as a measure of personality function.

d) General memory

Participants had their general memory assessed using the California Verbal Learning Test (CVLT) (Delis, 1987). This assessment has both short delay and long delay recall and recognition items. The long delay tests are administered with 20 minutes between presentation and test. The long delay recall and recognition items were administered following test of recall and recognition of the

slide/narrative series. For the purposes of subject matching, only free recall performance over the first five recall trials was included in analysis in this study.

e) TAS – 20 (Taylor et al., 1997; Bagby et al., 1994)

The TAS – 20 was used to initially screen potential participants. It is a revised and improved version of the TAS. Both scales (TAS & TAS-20) are highly correlated and demonstrate both internal reliability and test-retest reliability (Taylor et al., 1997; Bagby et al., 1994). The TAS – 20 has a more stable factor structure than the TAS because of the addition of several new items. The construction of the TAS-20 included elimination of TAS items found to have low magnitude corrected item/total correlation, high correlation with a social desirability scale or significant loadings on more than one factor (Taylor et al., 1997; Bagby et al., 1994). The cut-off scores used in this study are recommended by the authors of the TAS-20 as a result of empirical study (Taylor et al., 1997). They denote non-alexithymic and alexithymic individuals and have been employed in recent published studies of healthy young adults by the authors (see for example Parker et al., 1999). The questionnaire requires participants to respond to series of questions or statements by selecting one of 5 possible responses (1 = strongly disagree, 2 = moderately disagree, 3 = neither disagree nor agree, 4 = moderately agree, 5 = strongly agree). Examples of these questions/statements are provided below and the full TAS-20 is provided in Appendix 4.

e.g. "I prefer to just let things happen rather than to understand why they turned out that way"

"Being in touch with emotions is essential".

"I prefer to watch 'light' entertainment shows rather than psychological dramas".

4.2.2.2. Portapress Model – 2 (TNO-TPD Biomedical Instrumentation Amsterdam, The Netherlands)

Diastolic and systolic blood pressure along with heart rate information was recorded for each subject using a non-invasive continuous finger blood pressure measurement and recording system. Finger blood pressure was recorded using two preformed conical finger cuffs attached to the non-dominant hand such that the LED and photocell were symmetrically placed on each side of the fingers in the centre of the middle phalanx. Portapress is a battery operated portable monitor of finger arterial pressure that is worn by the subject. A 'height correction unit' compensates for hydrostatic pressure changes due to relatively slow movement of the hand. In addition, to allow prolonged ambulatory monitoring, the device automatically alternates the measurement between two adjacent fingers at an adjustable interval (1, 15 30 or 60 minutes - for our purposes, this interval was set at 15 minutes). When a measurement is activated the device becomes automatic and will continue without the need for operator intervention. The full finger pressure waveform, the height correction value, and different run time messages and markers are stored by the device on a 'flash memory card' stored in a belt worn around the subject's waist. Beat to beat results are available following data transfer from flash memory card to PC (Dell Optiflex GX1). Subsequent beat-to-beat analysis using BeatScope software (TNO-TPD Biomedical Instrumentation, Amsterdam, The Netherlands) yields

values for a range of physiological variables accounting for height correction. Portapress apparatus has been validated in published studies of continuous stroke volume monitoring in humans under orthostatic stress (Harms et al., 1999).

4.2.2.3. Emotional stimuli: Slide/story presentation.

The slide stimuli employed in this study were similar to the material employed by Cahill and colleagues (Cahill, 1994) but differed in that only the 'emotional' slide narrative presentation was used. This protocol was identical to that employed by O'Carroll et al 1999(a), 1999(b). Participants were seated in a comfortable chair in a darkened, room while a series of 11 slides were projected for 20 seconds per slide, onto a white screen (6ft by 4ft) six feet from them. A short audio taped narration accompanied each slide (see Appendix 2 for this narrative).

For the purposes of analysis, the slide narrative presentation were divided into the three phases. The first phase contains essentially emotionally neutral information relating to the protagonists, to the mother and son leaving home to visit the father and their journey. Emotionally arousing information is introduced in the second phase concerning the car accident, the hospital and the subsequent surgery and the final phase deals with the aftermath of these events (the alternative arrangements that have to be made by the mother to collect her other child).

4.2.3. Procedure

Each subject, on arrival, completed the Stress Arousal checklist (see Appendix 5 for S/A checklist results) and was immediately connected to the Portapress apparatus for the initial baseline period of monitoring. Participants sat quietly for approximately 60 seconds while initial pulse and blood pressure were recorded (see Appendix 5 for these results). After this period of 60 seconds, the recording was terminated and the cuffs were left to deflate. However participants continued to 'wear' the belt and preformed cuffs to familiarize participants with the apparatus. Participants were then given the following information.

"You indicated on the questionnaire you completed before today that you sometimes experience no particular difficulty (low alexithymia group)/ particular difficulty (high alexithymia group) in identifying and naming your feelings. We want to investigate the performance of people who score high and low on the questionnaire on a number of tasks in the lab."

Following this brief introduction demographic and other details were collected (e.g. age, D.O.B, student/non student, cash or credit desired etc). In addition participants completed the CVLT followed by the EPQ and NART in counterbalanced order. On completion of the subject matching measures, baseline recording was initiated. This session was undertaken to a) familiarize participants further with the apparatus and b) to culminate in a 'relaxation' baseline recording. Participants were required to read a passage sub-vocally for 60 seconds, reading out

loud for 60 seconds followed this. Participants were then given the following instructions:

"now that the reading task is over, I would like you to close your eyes and try and relax as much as you possibly can. I would like you to try and clear your mind of anything you might be thinking of and I would also like you to take long, slow breaths"

Participants relaxed and sat quietly with their eyes closed for a period of 120 seconds and were then asked to remain relaxed while they opened their eyes and fixated on the area of wall directly in front of them where the slide series would later be projected. This period lasted for a further 120 seconds. The 'eyes open' period of recording was called the 'relaxation baseline' because participants received explicit instructions to aid relaxation both before and at the beginning of the period. In addition, participants were asked to adopt a pose similar to that adopted when slides were eventually presented during this period (i.e. sitting quietly while staring at the projection area). During the subsequent slide/narrative stimulus presentation, peripheral pulse and blood pressure were monitored using Portapress. Systolic and diastolic blood pressure along with heart rate readings were taken continuously during each slide presentation and participants were required to press a small white 'marker' button on the Portapress belt when each slide was introduced on the pre-recorded narrative. Pressing this button placed a marker on the beat-to-beat results file, which was used for later analysis. Immediately following the completion of the slide/narrative presentation, participants were required to indicate how emotionally

arousing they found the slide presentation by placing a mark on a visual analogue scale ranging from 1 (not at all emotional) to 10 (highly emotional). Participants then completed the Stress Arousal checklist for a second time indicating their 'feelings and mood' at that particular time. Participants then had their heart rate and blood pressure recorded again using Portapress. Before departure, participants were asked not to discuss the slide stimulus materials with others during the week intervening. The reason given was to minimize the possibility of other potential participants expecting certain slides. Participants were told that expecting certain slides might affect blood pressure readings and therefore interfere with results. The other reason for asking participants not to discuss the stimulus materials (and this reason was not communicated to participants) was to minimize the possibility of rehearsal of the to-be –remembered stimuli during the intervening week. At no time during the initial session were the subsequent memory test or the slides communicated to participants.

4.2.3.1 Second session - 7-day interval: Memory assessments.

One week following the initial session participants returned for a final session. Participants again completed an initial stress and arousal checklist and had blood pressure and rate information recorded using the Portapress apparatus (Appendix 5). This procedure was identical to that employed at the outset of the initial session. Participants were told at the end of the first session that this final session would involve administration of a further series of 'pencil and paper' type assessments similar to those carried out in the first session. They were also told that

the session was required to reduce the 'workload' in the first session as well as to allow the collection of comparative blood pressure and heart readings on more than one occasion. Following the completion of the Stress-Arousal checklist and baseline Portapress recording an essentially 'surprise' memory test for the slide series was administered. The initial test of recall for the slide narrative series involved participants being asked to freely recall as many of the slides as possible from the presentation a week earlier. The instructions given to participants were identical to those given to participants in other studies employing these stimuli both in the USA and UK. They were asked to describe them in as much detail as possible and were prompted to recall both the story line as well as particular details, (e.g. 'colour of clothing' and the 'direction that people were walking' were given as examples of the kinds of details a subject might recall). Participants were told to take as long as they needed and following a response of 'that is all I can remember' were reminded that they had seen a total of 11 slides. The participants were then asked to repeat the free recall exercise so that the experimenter could "assess which of those 11 slides you have any memory of seeing" participants were asked to mention as many of the eleven as they could remember, describing each in detail. The justification for the repeated recall assessment was so the experimenter could confidently conclude that a subject had remembered a given slide.

Following the free recall memory assessment, the participants were required to verbally respond to a series of multiple choice memory questions designed to assess recognition memory (see Appendix 3. for the recognition memory assessment). Again, instructions for this task closely followed a script reminding

participants of the number of slides, the number of likely multiple choice questions per slide and the slide number each question referred to.

4.2.4. Analysis

Between-group differences on potential confounding variables and total recall and recognition scores between the two experimental groups were analyzed using one-way ANOVA. Pearson's correlations were employed to explore the relationships between any subject matching measures found to differ between groups and subsequent memory performance. Blood pressure, heart rate, free recall and recognition memory scores were also analyzed for the three distinct phases of the slide narrative series using repeated measures ANOVA (within-subject factor = story phase (1-3). Between-subject factor = High/low alexithymia score). Planned post hoc comparisons included LSD (for between group variables) and paired sample t-tests (for within-subject comparisons).

As in the previous chapters, if the within-participants variable had more than two levels, Mauchly's test of Sphericity was conducted on the within-subject variable. The significance of Mauchly's W would indicate that the assumption of equivalent correlations between the variables in the ANOVA is not supported. In the event of this analysis being significant, and according to current convention (Brace et al., 2000, p192), a multivariate criterion of Wilks' Lambda would be adopted for

the within-subject factor in the analysis. In the event of this analysis being non-significant, then the univariate results would be reported.

4.3. Results

4.3.1. Potentially confounding between group variables (Table 4.1.)

The two groups in this study (high alexithymic and low alexithymic) were well matched on potentially confounding variables (see Table 4.1.). These included age, IQ as expressed by their error score on the NART, psychoticism , extroversion and lie personality scores of the EPQ and neutral word memory test scores (CVLT). Significant differences did exist between the groups on the neuroticism EPQ score (neuroticism – $F = 4.59$, $p = .04$). However, this variable did not correlate with physiological indices of arousal at baseline ($r = .42$, $p = .05$) or during the presentation of the to be remembered stimulus materials (e.g. Systolic blood pressure at phase 1 of the slide presentation ($r = .17$, $p = .45$). at phase 2 ($r = -.02$, $p = .93$) and at phase 3 ($r = -.01$, $p = .98$). There was also no significant correlation between the neuroticism variable and the total recall and recognition scores at one-week interval (recall: -.01, $p = .97$; recognition: -.36, $p = .08$). The neuroticism variable, although significantly different between groups, was not significantly associated with the main variables of interest in this study. Therefore it was not entered as a covariate in subsequent analysis involving the main variables of interest in this study.

Table 4.1. Comparison of the two subject groups on potential confounding variables. Mean (SD).

	High alexithymia	Low alexithymia	F	p
Age	19.25 (1.48)	19.92 (1.56)	**1.15**	**.30**
Baseline systolic bp.	117.85 (14.01)	109.49 (11.20)	**2.52**	**.13**
Baseline diastolic bp.	58.71 (9.89)	59.29 (7.38)	**0.03**	**.87**
Baseline heart rate	78.47 (10.98)	77.84 (10.17)	**0.03**	**.87**
CVLT A1-5	64.67 (5.88)	62.08 (10.60)	**0.55**	**.47**
N	7.92 (2.57)	5.50 (2.94)	**4.59**	**.04***
E	5.83 (3.64)	8.67 (2.93)	**4.41**	**.05**
P	3.25 (2.67)	3.33 (2.10)	**0.01**	**.93**
L	1.75 (1.42)	2 (2.05)	**0.12**	**.73**
NART error	19.33 (4.52)	5.44 (1.57)	**1.13**	**.30**

bp: Blood pressure. CVLT: California Verbal Learning Test – A1-5: total recall over first 5 presentations of 16 item word list. N: Eysenck Personality Questionnaire (EPQ) Neuroticism score. E: EPQ Extroversion score. P: EPQ Psychoticism score. L: EPQ Lie score. NART: National Adult Reading Test. Error: Error score.

4.3.2. Physiological and subjective responses:

4.3.2.1. Subjective responses

One – way ANOVA indicated that there was no significant difference between the high and low alexithymia groups on their subjective visual analogue style rating of the slide story presentation. [F (1, 22) = .08, p = .78. High alexithymia mean = 5.09/10 (SD = 2.30); Low alexithymia = 5.33/10 (SD = 1.83)]

To summarize, the rating of how emotionally arousing participants found the slide story presentation was equivalent in both groups, mid-way between the 'not at all emotional' end of the scale and 'highly emotional' end of the scale for both high and low groups.

4.3.2.2. Physiological responses during the relaxation baseline

Diastolic and systolic blood pressure along with heart rate was recorded during the relaxation baseline period of monitoring for all participants. One – Way ANOVA revealed no significant between group differences on these variables during the relaxation baseline (see Table 4.2. for these results). The standard deviation of each physiological variable is provided in Table 4.2 to indicate of the degree to which these variables 'fluctuated' during the relaxation period.

Table 4.2. Physiological responses during the relaxation baseline period

Relaxation Physiology		Mean (standard deviation)	One-way ANOVA
Systolic bp	High alexithymia	121.56 (13.51)	F (1, 22) = .77, P = .39
	Low alexithymia	116.98 (11.57)	
Systolic bp SD	High alexithymia	5.36 (2.45)	F (1, 22) = .21, P = .66
	Low alexithymia	4.98 (1.51)	
Diastolic bp	High alexithymia	64.18 (6.81)	F (1, 22) = .03, P = .86
	Low alexithymia	64.66 (6.38)	
Diastolic bp SD	High alexithymia	2.21 (.89)	F (1, 22) = .20, P = .66
	Low alexithymia	3.38 (.96)	
Heart rate	High alexithymia	77.10 (10.52)	F (1, 22) = .22, P = .64
	Low alexithymia	78.92 (7.91)	
Heart rate SD	High alexithymia	5.69 (1.03)	F (1, 22) = .69, P = .42
	Low alexithymia	6.49 (3.03)	

Table 4.2 indicates no significant differences existed between the high and low alexithymia groups in physiological parameters at baseline indicating a lack of 'tonic' differences between groups.

4.3.2.3. Deviation from baseline during presentation of to-be-remembered stimuli

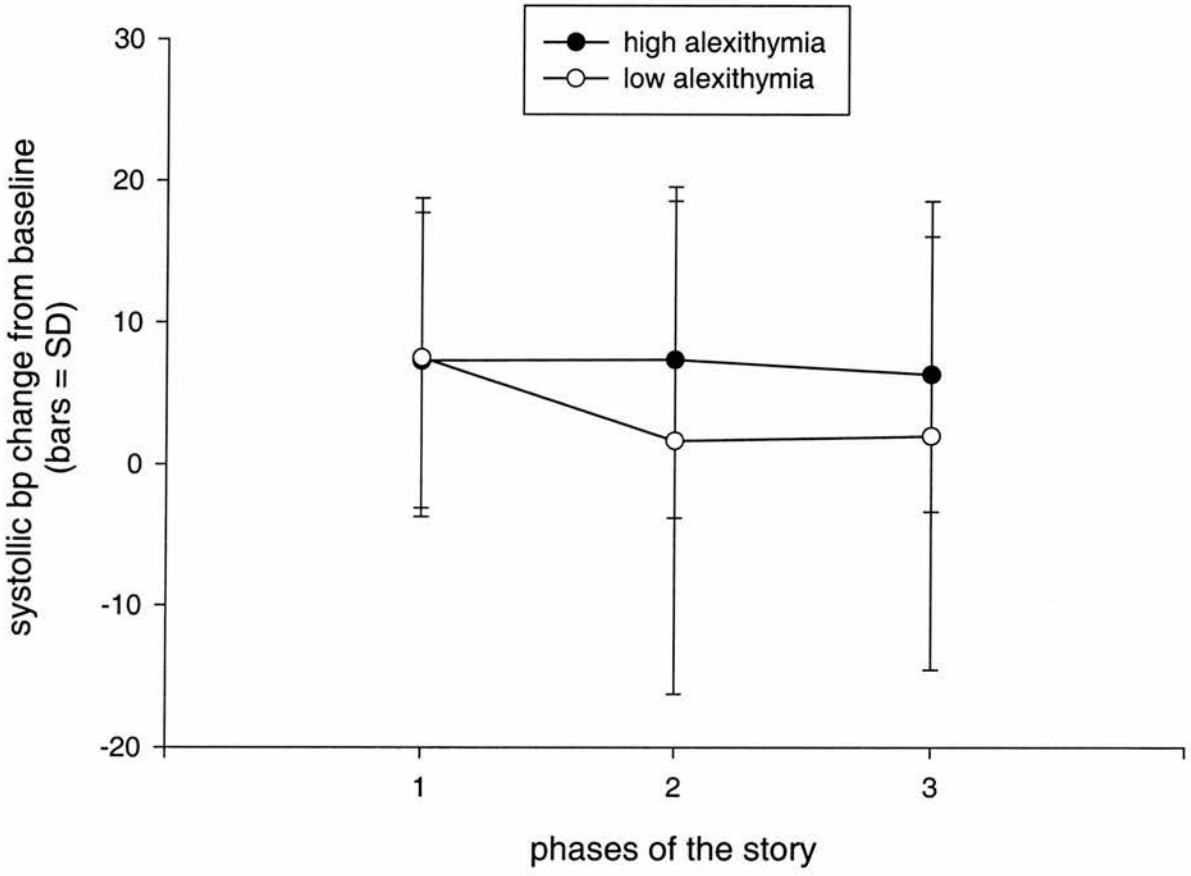
In order to assess the degree to which participants in high and low alexithymia groups changed from the relaxation baseline in responding to the emotional stimuli, repeated measures ANOVA was performed on difference values (presentation minus baseline) between systolic and diastolic blood pressure and heart rate during slide presentation and these values recorded during the relaxation baseline (see Figures 4.1, 4.2, 4.3). Mauchly's test of Sphericity was significant for the within group variable of story phase for both systolic and diastolic blood pressure [systolic: W (2) = .21, p = .01; diastolic: W (2) = .33, p = .01. Therefore, the multivariate criterion of Wilks' Lambda was used to test the within-subject variable of phase for both of these variables. There were no effects of story phase or group on systolic and diastolic blood pressure change from baseline scores and no significant story phase by group interactions [Systolic (Figure 4.1.) : Phase: F (2, 20) = 2.51, p = .11; group: F (1, 21) = .62, p = .44; group x phase: F (2, 42) = 1.43, p = .25. There was no effect of diastolic blood pressure - Diastolic [Figure. 4.2: phase: F (2, 20) = 2.73, p = .09; group: F (1, 21) = .11, p = .74; group x phase: F (2, 42) = 2.42, p = .10). There was no significant effect of story phase on change from heart rate baseline scores (Figure. 4.3) [F (2, 42) = 1.52, p = .23] and no group by phase interaction [F (2, 42) = .11, p = .88). However, there was a significant effect of group on heart rate change from baseline score (F (1, 21) = 6.71, p = .02) – see

Figure. 4.3. This indicates that the high alexithymia group had consistently reduced heart rate across the three phases of the slide story presentation relative to baseline.

4.3.2.3.1 – Comparison with relaxation baseline

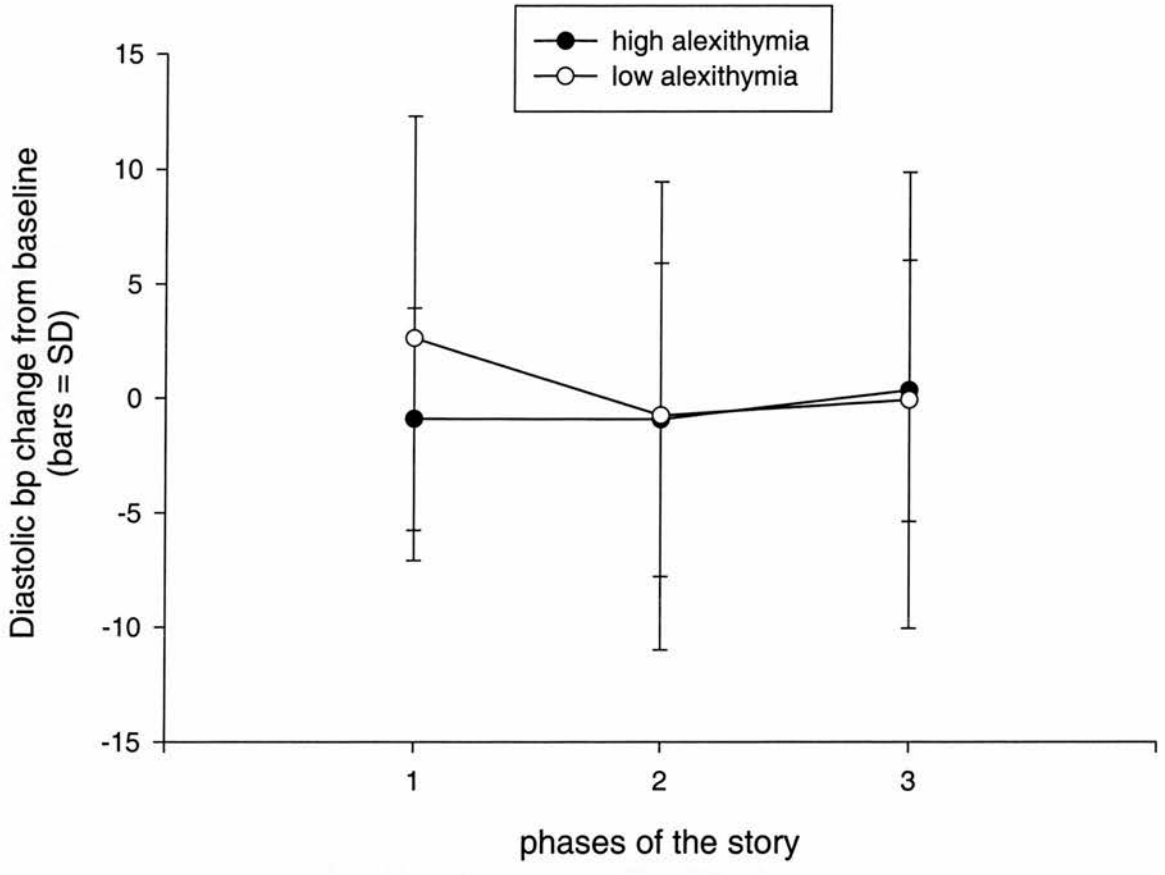
The low alexithymia group's heart rate during slide phases 1, 2 and 3 was significantly lower than this group's heart rate during the relaxation baseline which was 78.92 (SD = 7.9) [Phase 1: t (22) = -4.07, p = .01 (phase 1 mean = 73.76, sd = 8.3). Phase 2: t (22) = -5.45, p = .01 (phase 2 mean = 74.08, sd = 9.73). Phase 3: t (22) = -5.08, p = .01 (phase 3 mean = 74.78, sd = 9.14)]. In contrast, the high alexithymia group's heart rate during slide phases 1, 2 and 3 did not differ significantly from this group's relaxation baseline heart rate which was 77.10 (SD = 10.52) [Phase 1: t (10) = -.81, p = .44 (phase 1 mean = 75.67, sd = 13.60). Phase 2: t (10) = -.37, p = .72 (phase 2 mean = 76.50, sd = 11.38). Phase 3: t (10) = .24, p = .82 (phase 3 mean = 77.40, sd = 11.56)].

Figure 4.1. Systolic blood pressure change from baseline over the three slide phases



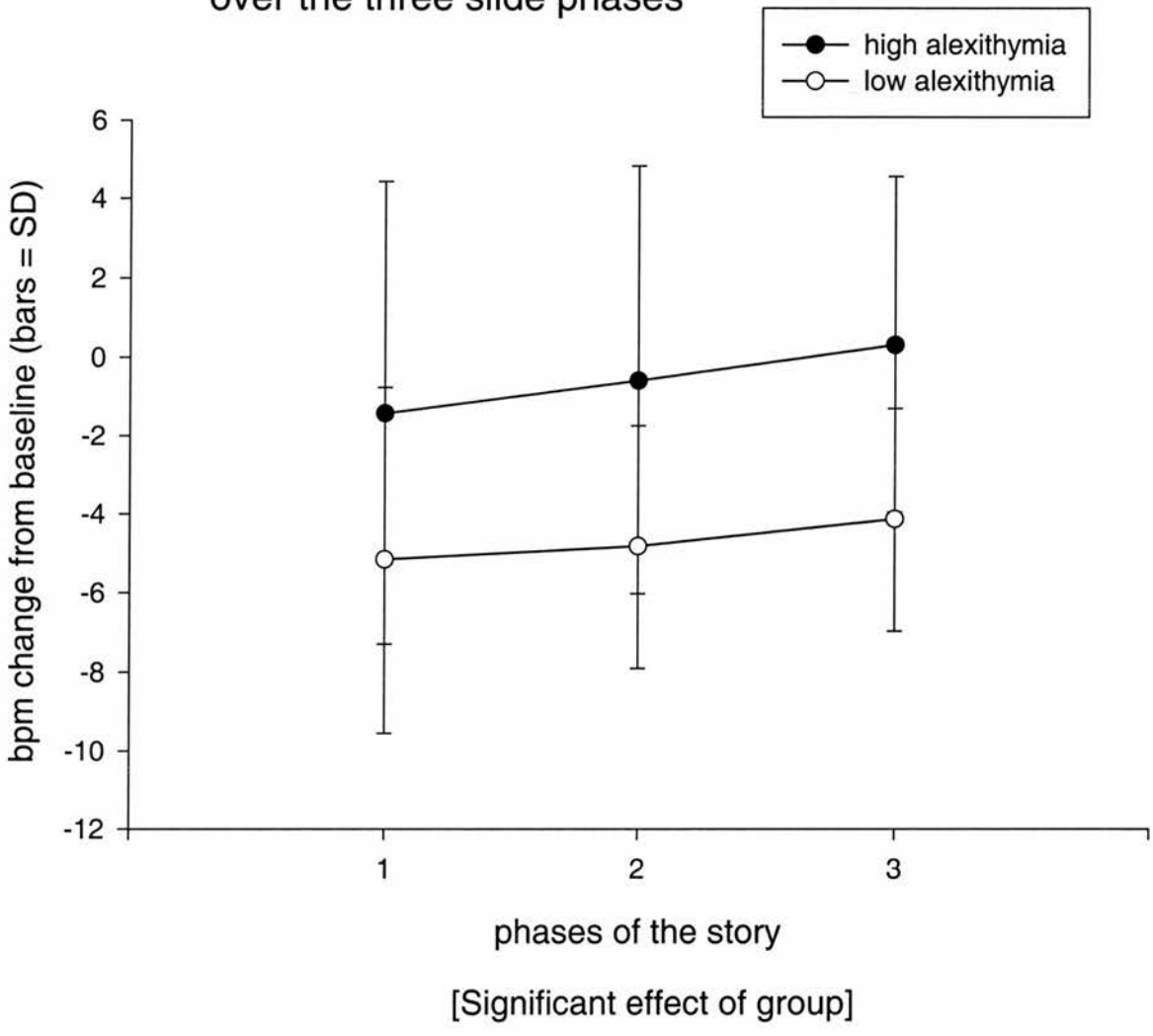
[No significant effects]

Figure 4.2. Diastolic blood pressure change from baseline over the three slide phases



[No significant effects]

Figure 4.3. Heart rate change from baseline (bpm) over the three slide phases



[Significant effect of group]

4.3.3. Memory Performance

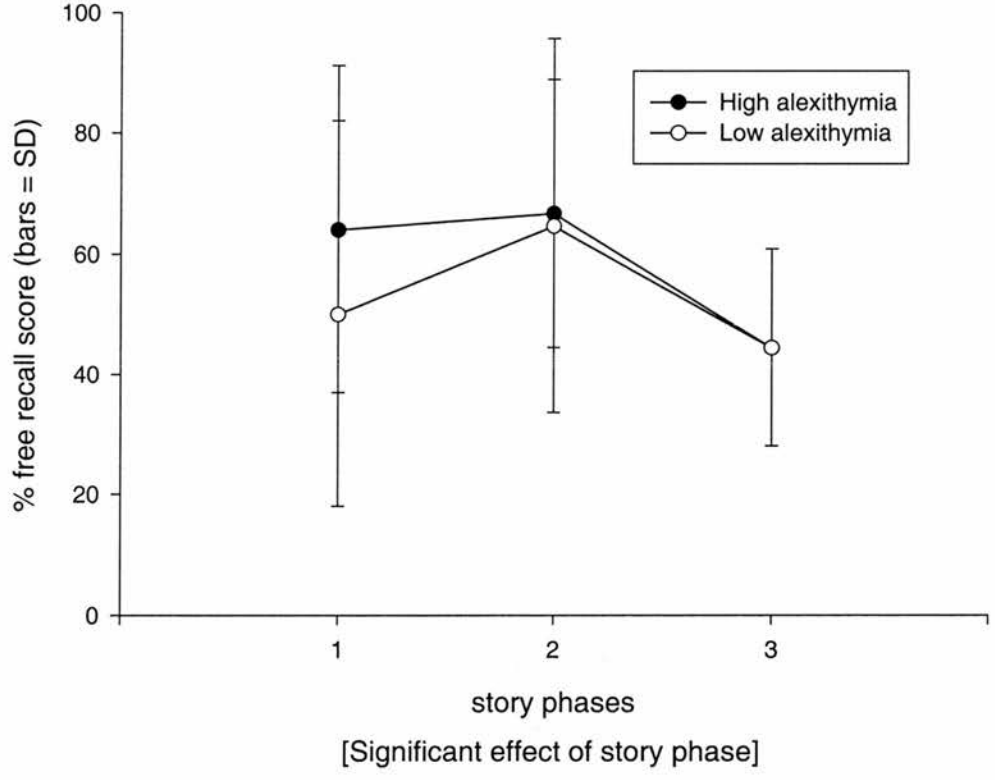
One week following stimulus presentation all participants, regardless of group returned to the laboratory and received a 'surprise' memory test consisting of two components: a free-recall memory test and a multiple choice recognition memory test for the stimuli presented one week previously.

There were no significant differences between groups of participants in terms of the total percentage number of slides recalled in the free recall test [One –way ANOVA – F (1, 23) = .57, p = .46. High alexithymia group mean = 59.85 (SD = 14.22), low alexithymia group = 54.55 (SD = 19.77)]. In addition there were no significant between group differences in total recognition memory performance (% correct) [F (1, 23) = .39, p = .54. High alexithymia = 59.86 (sd = 8.06), low alexithymia = 61.95 (SD = 8.2)].

Figures 4.4 and 4.5 display the free- recall performance and recognition memory performance means respectively for the high and low alexithymia groups. Mauchly's test of Sphericity was not significant for the within group variable of recall phase for either of the memory measures [Recall: W (2) = .99, p = .99; Recognition: W (2) = .92, p = .39] and therefore, univariate effects are reported. For percentage free recall scores, repeated measures ANOVA revealed a significant effect of story phase [F (2, 44) = 5.27, p = .01], no effect of group [F (1, 22) = .66, p = .42] and no group by story phase interaction [F (2, 44) = .72, p = .49]. Percent recall scores were significantly higher in phase 2 than in phase 3 only for the total

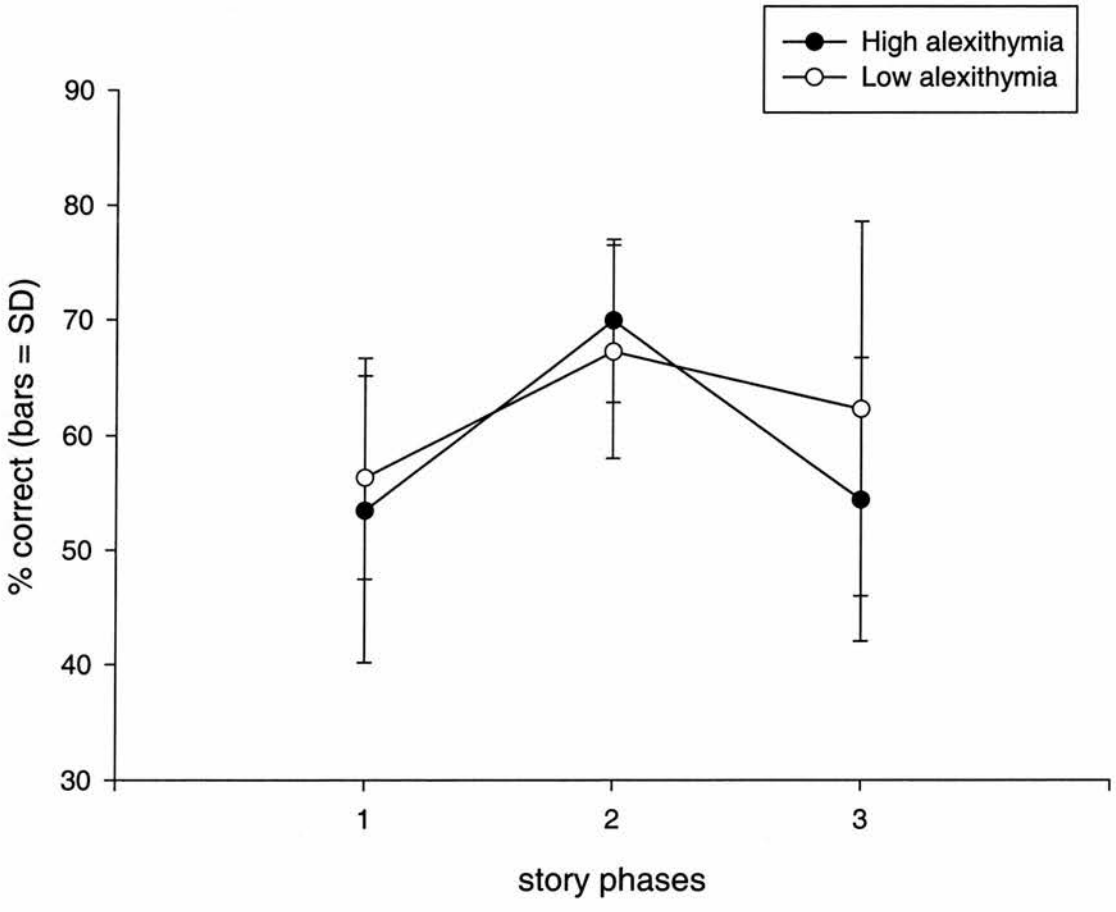
sample (t (23) = 3.24, p = .01). A similar pattern was observed with recognition memory performance (Figure 4.5.) with a highly significant effect of story phase on percent recognition memory scores [F (2, 44) = 12.38, p = .01], no significant effect of group [F (1, 22) = .63, p = .44] and no group by phase interaction [F (2, 44) = 1.70, p = .19]. The combined sample produced significantly higher scores for the second phase of the story compared to the first phase (t (23) = -5.64, p = .01) and the last phase (t (23) = 3.2, p = .01). This therefore confirms the normal peak in memory performance for phase 2 of the story.

Figure 4.4. Percent free recall memory performance for the three phases of the slide-story



[Significant effect of story phase]

Figure 4.5. Percent recognition memory performance for the three phases of the slide-story



[Significant effect of story phase]

4.4. Discussion

4.4.1. Were the predictions supported?

Two specific predictions were made in this study:

1. High alexithymics would demonstrate lower physiological reactivity to emotional stimuli than low alexithymics, and high alexithymics would produce lower memory scores compared to the low alexithymics. The results indicate that high alexithymics demonstrated lower levels of physiological reactivity to stimuli but did not differ from low alexithymics in terms of memory performance.
2. If high alexithymics showed lower subjective self-ratings of emotional response then it was predicted that low memory scores would be evident. A lack of difference in both memory scores and subjective self- ratings was observed.

4.4.2. Baseline differences in physiological responses

The results of this study indicate that alexithymia is not associated with higher 'tonic' or baseline levels of physiological activity in groups matched for potentially confounding variables. There were no significant differences between

high and low alexithymics on blood pressure and heart rate during a relaxation baseline period (see Table 4.3.).

4.4.3. Between-group physiological responses to slides

High alexithymia was associated with lower levels of physiological 'reactivity' in terms of heart rate (expressed as the change from heart rate relaxation period during stimulus presentation). During the presentation of the emotionally arousing slides, high alexithymics' heart rate did not differ significantly from relaxation baseline heart rate whereas, for low alexithymics, heart rate was significantly *lower* than heart rate relaxation baseline (see Figure 4.3). Including this study, there are now seven different studies that have found either no difference in reactivity related to alexithymia (Martin & Phil, 1986; Martin et al., 1986; Papciak et al., 1985) or lower levels of reactivity (Hyer et al., 1990, Nemiah et al., 1977; Wehmer et al., 1995). The present study defined reactivity in terms of the difference between heart rate response to the slide stimulus phases and heart rate responses during relaxation baseline and found lowered reactivity in alexithymia.

4.4.4. Within-group physiological responses to the phases

The participants in this study demonstrated a lack of physiological response to the different slide phases presented. This lack of physiological response to the emotionally arousing phase of the slide series is similar to the results of other studies (O'Carroll et al., 1999a/b). However, studies carried out with stimuli by Cahill and colleagues (1994) and by van Stegeren and colleagues (1998) have demonstrated

changes in physiological reactivity to the second, emotionally arousing phase of the slide series. In this study, the low alexithymic participants showed a greater heart rate response to the *entire* slide show compared to the high alexithymics. However, the direction of the change from baseline was *opposite* to that predicted. Essentially all participants showed a heart rate decrease during the presentation of the to-be-remembered stimuli relative to baseline. Low alexithymics showed a greater decrease than high alexithymics. This decrease is puzzling in the light of current literature. Bradycardia (heart rate slowing) has been detected in the emotionally arousing second phase of the same stimuli in other published studies [Van Stegeren et al 1998, Cahill et al 1994 (not reported in published findings)]. Other studies (O'Carroll et al 1999a) found no evidence of a change in heart rate between the neutral and emotional phases. On the surface, no heart rate differences, or heart rate slowing for the emotional versus the neutral elements of the story would appear not to be in keeping with the assertion that phase two of the slide series produces an *increase* in physiological arousal. However, some researchers argue that bradycardia is associated with mild emotional arousal (Lacey & Lacey, 1974, Palomba et al 1997). The present study has found bradycardia over all three phases of the slide series. The high alexithymics show no significant change from baseline heart rate during the slide presentations. Low alexithymics show a significant reduction in heart rate during the emotive slide presentation compared to baseline. This finding could possibly be interpreted in terms of low alexithymics being more emotionally aroused in response to the entire stimulus presentation.

4.4.5. Subjective responses to slides

No significant differences were evident between the high and low alexithymia groups in terms of their subjective self-ratings of how emotionally arousing they found the slide presentation as a whole. This rating was made immediately following the slide presentation. This finding is in keeping with previous research that has demonstrated significant differences between high and low alexithymics in terms of physiological responses but no differences in subjective measures such as anxiety self-ratings (Rabavilaz, 1997), and self reported mood state (Papciak et al., 1985). It would appear that the current study has provided further support for the "lack of normal reciprocal relationships between psychic and somatic components of the affective system" in alexithymia (Nemiah et al., 1977). For example, the current study found no evidence of differences in subjective, self rated responses to the slide presentations between the high and low alexithymic groups. However there was evidence of significant differences in the cardiac responses of high and low alexithymic groups in response to the slide presentations. This "de-coupling" effect whereby the physiological and subjective indices of arousal are dissociated, provides an opportunity to discover the degree to which subsequent memory performance depends upon either the physiological or subjective element of the decoupled response.

4.4.6. Memory performance

This study has assessed memory in high and low alexithymics comparing neutral and emotional memory. The lack of heart rate reactivity to the 'to-be – remembered' stimuli in the high compared to the low alexithymia groups in this study does not translate into impoverished memory for those stimuli in high alexithymics. We demonstrated the expected significant effects of story phase in both recall and recognition memory tasks, such that all participants remembered most material from the middle, emotive phase compared to either the first or the last story phases. However, we did not demonstrate any differences in recall or recognition memory scores between high alexithymics and low alexithymics, or any group by phase interactions on memory performance. This indicates that high and low alexithymics did not differ on either neutral or emotional memory performance in this study.

4.4.7. The relationship between subjective emotional responses and memory

There were no significant differences between the subjective ratings of the slide story between high and low alexithymic groups. There was also no significant difference in memory performance (recall or recognition) between high and low alexithymics. According to source of arousal theories, general levels of physiological arousal do not predict memory performance, but specifically emotional arousal in response to the 'to be remembered' stimulus should result in higher memory scores for that stimulus. The results of the present study support source of arousal theories in that subjective ratings of the 'emotionality' of the to-

be- remembered stimuli did not differ and subsequent memory performance remained the same for both groups in both memory tasks. However difficulties emerge with this interpretation of the findings given the fact that the groups *did* differ significantly in the physiological reaction (heart rate) to the to-be-remembered stimuli.

4.4.8. The relationship between physiological reactivity and memory

A problem for source of arousal theory in this study relates to the finding that low alexithymics showed evidence of a greater *reduction* from relaxation baseline heart rate than high alexithymics when the to-be-remembered stimuli were presented. This change from baseline during stimulus presentation is a widely used measure of 'physiological reactivity' or arousal to 'extrinsic emotional elicitors' (Wehmer et al., 1995). It is an indication of the degree of arousal elicited by the stimulus presented. The source of the physiological arousal may, in this case, be the stimulus present when arousal changed from the original relaxation baseline value. If this is the case, the change from baseline heart rate value should interact with memory performance, according to source of arousal theories. This is because the physiological arousal is tied to the to-be –remembered stimulus and is not 'free floating' like the physiological arousal elicited by exercise for example (Libkuman et al., 1999). Low alexithymics produced lower heart rate compared to relaxation baseline when the stimuli were presented in the present study. This should, perhaps, have resulted in lower memory scores for all phases of the slide presentation in low

alexithymics compared to high alexithymics. This is based on the assumption that low alexithymics were less physiologically aroused by the slides and therefore less affected by them. However, as reviewed above, heart rate slowing is sometimes associated with mild emotional arousal which, according to theories linking arousal to the source of the arousal (ie in this case the emotional second phase) in predicting memory should have resulted in *better* memory performance for the second 'emotional' phase of the story presentation (Libkuman et al., 1999; Cahill et al., 1994; van Stegeren et al., 1998). We observed heart rate deceleration across all three phases which would indicate that heart rate changes in this study in response to slides were not story phase specific. It seems that the role of physiological arousal in terms of predicting memory performance is difficult to determine in this study. We found no differences in subjective responses, differences in cardiac responses but no between group differences in subsequent memory performance.

4.4.9. Possible explanations

Alternative explanations are that physiological arousal was not associated with memory in this study because, even given the differences in heart rate change from baseline between the groups in this study, there were no differences between the groups on memory scores. Perhaps only the subjective emotional reaction is predictive of later memory performance for the stimuli used in this study. This conclusion is difficult to draw from this study alone because the requisite evidence would need to be a reliable double dissociation between subjective and physiological

arousal in terms of memory scores. In other words, subjective arousal should vary with memory while physiological arousal should not. This study however showed differences in physiological responses, no difference in subjective responses and no differences in memory. It is possible that the lack of difference in the memory scores would still be evident even with a significant difference in subjective reaction *and* physiological response. It seems necessary to demonstrate reliable between-group differences in both subjective emotional reactions to stimuli and memory performance, without between-group differences in physiological responses before it can be claimed that subjective emotional reactions to stimuli influence memory while physiological reactions do not. It is possible that both physiological and subjective responses to stimuli interact to affect memory performance. Nevertheless Chapter 2 of this thesis demonstrated that subjective ratings of arousal predicted memory performance for word stimuli while physiological responses to the same stimuli did not. The evidence from this chapter provides initial support for the theory that subjective emotional reactions to stimuli predict memory more reliably than physiological arousal to that same material in the laboratory.

4.4.10. Future studies

The current study examined the effects of alexithymic tendencies on subjective and physiological responses to a series of to-be-remembered stimuli. Memory assessments were explicit tests of episodic recall and recognition and no assessments *comparing* the effects of implicit and explicit emotional memory were

employed. It is possible that given the subtle between group differences in cardiac responses to to-be-remembered stimuli demonstrated in this study, other less conscious forms of emotional processing/memory may be affected in alexithymia. Future studies could assess word memory performance in alexithymia using the word-stem completion task, a widely used implicit memory assessment method (see Banos et al., 2001 for a recent study employing these materials). This task requires participants to either generate words from stems by attempting to explicitly recall words shown to them previously or by generating the first word that 'comes to mind' when provided with the stem at the memory test (i.e. the implicit memory test instructions do not refer to the previous learning trials). Conceivably it could be possible to adapt the Cahill slide stimuli to be used as a pictorial analogue of word stem completion paradigms. Elements of the slides could be presented to participants during the memory assessment and participants could be required to generate *other* elements of the slides, either in terms of an explicit attempt to recall elements presented one-week previously (explicit condition) or in terms of an implicit task whereby participants recall anything that comes to mind when shown a given slide segment (implicit condition). Half of the participants in each alexithymia group could be assessed at the one- week interval using either the implicit or the explicit memory task. Adapting the slide stimuli in this way would allow both implicit and explicit emotional memory to be assessed in high and low alexithymic individuals utilizing a cross-over design.

4.4.11. Summary

In summary, participants in this study were randomly assigned to 2 groups based on their extreme scores on the Toronto Alexithymia Scale.

a) There was no evidence to indicate that high and low alexithymics differed in baseline or tonic physiological responses.

b) There was no evidence to indicate that high and low alexithymics differed in their subjective self-rated emotional responses to the slide story stimuli presented.

c) There was also no difference in subsequent memory performance for the slide story between high and low alexithymics.

d) Low alexithymics showed greater heart rate reduction from baseline when the slide stimuli were presented compared to high alexithymics (Figure. 4.3.). This indicates that high alexithymics are less physiologically reactive to stimuli presented in the laboratory compared to low alexithymics, but this had no impact on subject memory for emotional material.

Chapter 5

Physiological and Subjective Correlates of Memory for Emotionally Arousing Visual and Auditory Material: Does Distinctiveness Improve Emotional Memory?

5.1 Introduction

In Chapter 2, verbal memory performance was assessed in healthy adults. In particular, the study attempted to identify the memory changes that occur over time for neutral and emotional words that were matched for length and frequency of occurrence in the English language. There was no evidence of a memory 'incubation' effect for emotional compared to neutral words.

In the present chapter, using different stimuli (pictorial images and sounds instead of words), we aimed to address two questions concerning what it is about a stimulus that ensures it a privileged place in memory. The first question concerned the role played by the rated *arousal* and *valence* of a stimulus in terms of later memory for that stimulus. Chapter 2 dealt with words rated in terms of arousal only and it is clear that an emotional response, although possibly primarily concerned with levels of arousal (Bradley et al, 1992), may also be considered pleasant or unpleasant (valence). To what extent do these two dimensions (valence/pleasantness and arousal) have separate or combined effects on memory? The second question concerned the relationship between the effects

of emotion on memory and the effect of 'unusualness' or 'distinctiveness' on memory. It is clear that any consideration of the way emotional arousal influences memory should include a consideration of the ways in which a stimulus elicits an arousal response.

5.1.1. Question 1 – What are the effects of 'unusualness' or 'distinctiveness' on memory for emotional material?

In Chapter 2 we observed a dissociation between physiological responses (which were similar for frequency-matched unusual and taboo words) and memory performance (we found memory to be superior for words rated as above a verbal rating threshold). This leads to the suggestion that improvements in memory over time depend, not on whether a stimulus is distinctive, but whether or not a stimulus is emotionally arousing in nature. However, it is clear that distinctiveness and emotionality are closely entwined. For example, it is arguably the case that a stimulus that would elicit a pronounced physiological arousal response in an expected context may well not do so in another context, where the stimulus is not expected (i.e. a context in which the stimulus is distinctive).

The study reported in this chapter attempted to discover what happens in terms of memory performance when a visual stimulus is made either incongruent or congruent by presenting it with a sound that either matches the subject matter of the image or does not match the subject matter of the image. We then attempted to discover what happens in terms of memory performance when an emotional stimulus is made either congruent or incongruent when it is presented to participants.

Psychological studies of memory for emotional events have directly studied the effects of emotion and unusualness on memory. Christianson and Loftus (1991) tested participants' memory for depicted images in slides. In the 'emotional' condition, participants' memories were tested for central and peripheral details of a road-traffic- accident scene depicting a woman lying critically injured in the middle of a road by her bicycle. In the neutral version, the woman was depicted riding her bicycle in the road and in the 'unusual' condition, the same woman was depicted walking in the middle of the road carrying her bicycle on her shoulder. Memory for the central detail of the emotional scene (colour of the woman's top) was better than memory for the peripheral detail (colour of a parked car in the distance). In the unusual condition however, participants performed poorly on both the central and peripheral detail. This study indicates that the effects of emotion on memory are different from the effects of 'unusualness' on memory and that emotional but not unusual material is associated with an increase in memory for central as opposed to peripheral details. The interpretation of this finding (Christianson & Loftus, 1991) was that the memory enhancing effects of emotional arousal cannot be completely explained by the unusualness or distinctiveness of the 'emotional' scene. However, the Christianson and Loftus study compared the memory of participants who viewed either neutral, unusual or emotional visual scenes and did not vary the degree to which the emotional scene itself was also unusual. It is possible to suggest that incongruence/unusualness may be an inherent part of the emotional scene itself. For example, the distinctiveness of the emotional visual scene in the Christianson & Loftus study (i.e. the bicycle accident) was qualitatively different from the distinctiveness in the unusual scene (i.e. the

bicycle being carried). It is difficult to claim that the memory performance of participants viewing the emotional scene was not due, in whole or in part to the distinctiveness inherent in the emotional scene. It is necessary to be able to compare memory for the same emotionally arousing visual scene under conditions where the scene can be described as 'usual' and under conditions where the scene can be described as 'unusual'. One way of achieving 'usualness' and 'unusualness' in an emotional scene is by combining the visual scene with another stimulus (i.e. a sound) that can be described as either congruent or incongruent ('in-keeping' or 'not in-keeping') with the visual scene. A presentation could be described as incongruent if the visual scene is not in an appropriate auditory context. An example is a picture of a car accident in the context of the sounds of laughter compared with a picture of a car accident in the context of the sound of the collision.

Physiological evidence on the changes that occur during learning in non-human animals implicates the notion of stimulus incongruence as important in the process of emotional reactions to potentiality dangerous stimuli. Long-term potentiation occurs in NMDA receptors and has been implicated in memory formation (Kelso & Brown, 1986). NMDA receptors have been found in the amygdala suggesting that this form of memory may occur in this structure. Single cell recording in the amygdala has been studied by Bordi and colleagues (1992; 1994) while rats are presented with a tone and receiving a shock. It has been demonstrated that every cell responding to auditory stimuli in the lateral nucleus of amygdala also responds to shock (Romanski et al., 1993). This finding suggests that the components and mechanisms of classical conditioning of fear responses may occur in the lateral nucleus (AL) of the amygdala. When

studying acoustically stimulated cells, Bordi & LeDoux (1992) found two classes of cells, those that were consistently responsive and those that were habituating. The existence of cells that habituate to sound in the lateral nucleus; i.e. cells that eventually stop responding when a sound is repeatedly presented, suggests that these cells may serve to support mechanisms that respond to sounds that are distinctive or unexpected. These habituating cells made up approximately 60% of the cells examined in the AL (Bordi & LeDoux, 1992). The consistently responsive cells in the lateral nucleus were found to have high intensity thresholds (above 10kHz). This would suggest that these cells can only be activated by loud sounds.

Evidence indicates that cells exist in the lateral nucleus of the amygdala that may play a role in detecting unusual sounds. The notion that associative long-term potentiation occurs in the lateral nucleus and that information about the tone and the shock in classical conditioning converge in these cells suggests that sound and shock pairing at these cells might serve to reduce habituation (by the action of the Hebb rule perhaps). Such a reduction would allow the cells to respond to, rather than ignore significant, unexpected stimuli. The earlier observation that environment plays an important part in the expression of classically conditioned responses is underpinned by observations at the cellular level. For example, the sound of a poisonous snake could, arguably be classified as distinctive while walking in woodland and perhaps be seen as more congruent if heard in the context of a reptile house at a zoo. Equally, a loud 'incongruent hiss' in a woodland context may well signal the closeness and therefore the relative threat of attack. In such circumstances, the congruence of the stimulus with the surrounding context might determine the likelihood of danger. The

degree of incongruence of a stimulus with its context may provide an important cue at a cellular level and at a behavioural level to signal an arousal response. It would also seem to confer an evolutionary advantage to ensure that threatening/arousing events are allocated a privileged place in memory. The idea of stimulus 'congruence' interacting with the pleasantness/valence of stimuli in predicting memory performance appears to be a testable hypothesis with human participants.

The notion of cells that habituate to sound implicate mechanisms at the cellular level that may respond to auditory stimuli that are unusual, different or new. The fact that this mechanism may exist in the amygdala, an area of the brain intimately linked with the regulation of the autonomic nervous system leads to the possibility that incongruent sounds are detected by this structure in order to instigate the physiological changes that underpin avoidance behaviors to potential threat. The time- limited role of the amygdala in influencing memory storage in other brain areas has been documented (Packard et al., 1994) and has implications for the enhanced storage of incongruent stimuli that are emotionally arousing in nature. On the basis of physiological and psychological evidence it is expected that interactions should be evident between emotional arousal and congruence such that stimuli that are a) *incongruent* or unusual, b) arousing and c) unpleasant would be better remembered than *congruent* arousing and unpleasant stimuli.

5.1.2. Question 2. - What are the effects of stimulus arousal and valence on memory? Categorical and dimensional perspectives.

An ongoing debate in much of emotion research concerns the degree to which emotion can best be understood in psychological and neuropsychological research. One approach argues that emotion can best be understood in terms of the discrete categories used in every day parlance [e.g. categories like 'sadness', 'anger', 'fear' and 'disgust' (Ekman, 1972, 1982; Izard, 1971; Calder et al., 1996)]. Evidence in support of this approach comes from studies of cross-cultural similarities in the recognition of certain categories of facial emotion (Ekman 1972, 1982). Support also comes from cases of impairment in the recognition of certain categories of emotional facial expression following selective brain damage (Calder et al., 1996).

The other approach is to suggest that emotions vary in a more subtle way along underlying dimensions like affective valence and arousal. (Russell, 1980; Tellegen, 1985; Lang et al., 1990; Bradley et al., 1992). Evidence to support this view comes from the intuitive observation that considerable variations exist within expression categories. For example, within the broad category of the 'fear' facial expression category may be more subtle dimensions like 'nervous anticipation', 'apprehensiveness' or even 'abject terror'. Subtle within-category differences lead to the possibility that emotional tone changes on a continuum. Studies have demonstrated that certain bipolar factors like pleasantness and intensity account for most of the variance in judgements of affective stimuli (Osgood et al, 1957). Similar evidence comes from studies of patients with

amygdala damage, which reveal impairment in the recognition of fearful facial expressions (Calder et al., 1996). A recent Positron Emission Tomography (PET) activation study of the healthy amygdala has raised questions for theories linking this structure with the recognition of 'fear' specifically. Hamann et al (1999) found that amygdala activation relates to enhanced memory for arousing stimuli *regardless* of the stimulus valence (i.e. positive or negative) suggesting that it may be more involved in arousal mediated processes in general rather than in discrete categories of emotion.

In the present study, we investigated the interaction of stimulus valence and arousal in relation to memory. We grouped stimuli into valence and arousal categories such that, although each stimulus had been rated in terms of dimensions of valence and arousal, the stimuli were grouped in terms of whether the ratings of valence and arousal had been high or low. Studies measuring both valence and arousal ratings in response to images (Bradley et al., 1992; Hamann et al, 1999) have found that arousal rather than valence influences long-term memory for pictorial stimuli. Bradley and colleagues found that pictures rated as highly arousing were remembered better than low arousal pictures at immediate and delayed (one year) free recall. Reaction times to 'high arousal' previously encoded items were faster than previously encoded low arousal items. Pleasantness (valence) affected reaction times only if the stimulus had not been encoded earlier. This led the authors to suggest that although both arousal and valence dimensions are processed at initial encoding, the arousal dimension rather than the valence dimension of an image predicts long-term memory performance. If this were the case, we would expect to see a clear relationship between participants' self-rating of arousal in response to a stimulus and later

memory performance for that stimulus. On the other hand, ratings of valence in response to a given stimulus should not relate to memory in this way. However, it is also possible that self-ratings of arousal affect memory only in certain circumstances, for example, when the arousal rating is combined with a given valence rating. It is possible that highly arousing and *pleasant* images are remembered less well than highly arousing and *unpleasant* images. Low valence, high arousal images could be interpreted as more threatening than high valence, high arousal images. There would seem to be a clear evolutionary advantage to selectively encode and remember threatening stimuli rather than non-threatening stimuli. Both images (the high valence image and the low valence image) are rated as being highly arousing but are very different in qualitative content as represented by the interaction of arousal and valence rating. Combining valence and arousal in this way allows the formation of categories, but not in the traditional sense (i.e. categories of 'fear' 'disgust' 'anger' 'happiness' etc). The emotion categories of fear and anger for example could be subsumed into the category 'low valence, high arousal'. Essentially, the terms 'anger' and 'fear' become labels to represent different combinations of valence and arousal dimensions. The dimensions of valence and arousal have been described as the 'primary' dimensions inherent in emotional stimuli (Bradley et al., 1992), and have been found to account for most of the variability in judgments of affective text as outlined above (Osgood et al., 1957). Valence and arousal also 'map' easily onto behavioural dimensions of direction (approach/avoidance) and vigor (mobilization) advocated by biphasic organisation theories of emotional responses (Hebb, 1949; Konorski, 1967; Lang et al., 1990).

If the interaction of valence and arousal are critical in emotional processing and memory then different memory performance should be evident between categories of previously rated stimuli based on the combination of valence and arousal levels within categories. For example, a low valence high arousal rated image may be remembered differently from a high valence high arousal category image. This is because, although both categories have been rated as being highly arousing, they are nevertheless different in as far as the two have been rated differently in terms of valence. On the other hand, both of the above mentioned categories contain images that have received high ratings of arousal regardless of valence. Therefore, according to arousal based memory findings outlined above (Bradley et al., 1992), there should be no difference in memory performance for the two categories of images because it is mainly arousal that affects long-term recall.

5.1.3. Does subjective or physiological arousal better predict memory?

Arousal is often defined in a number of ways in psychological studies of emotion. One view is that arousal is a unitary process characterized by the "excitation of the individual as a whole" (Duffy, 1963 – p3). The other view is that arousal is a more complex multidimensional process with behavioural, cognitive as well as physiological components (Lacey, 1967). Whereas a wealth of experimental data exists that claim to study the effects of arousal on memory (see Chapter 1), relatively few studies have directly compared the differential effects of physiological arousal and subjective arousal on memory performance.

The first definition of arousal is 'physiological' and involves manipulating bodily responses (e.g. heart rate) by either exposing the subject to severe and extreme traumatic experience or manipulating physiological arousal in a less source dependent way via exercise before and during the viewing of the to be remembered stimuli for example. The second definition involves the collection of physiological and subjective emotional reactions to stimuli. Physiological reactions elicited in the laboratory in response to certain stimuli are seldom similar to the physiological reactions in real-life responses to severe trauma. Ethical considerations limit the degree to which trauma can be 'reproduced' in laboratory based studies of the effects of both subjective and physiological reactions on memory. Laboratory studies have attempted to manipulate physiological arousal in other ways, via exercise for example (Libkuman et al 1999). Such studies have led to the conclusion that subjective arousal rather than physiological arousal is associated with heightened memory performance.

However, it appears that in order to compare the role of subjective and physiological arousal in memory, both must be elicited by a similar method and be source dependent. The study reported in the this chapter aimed to record both physiological responses (heart rate variability and galvanic skin response) and subjective self-ratings (arousal and valence) in response to a range of emotional and neutral stimuli in an attempt to determine the degree to which either one or the other predicted memory performance.

5.1.4. Summary of study predictions:

1. If long-term memory performance is preferentially affected by the dimension of arousal, then participants exposed to categories of stimuli, (which include arousal, and valence rated items) should remember more stimuli from the categories containing high arousal items regardless of valence (pleasantness).
2. It is suggested that memory performance is preferentially affected by the interaction between valence and arousal. From an evolutionary perspective, it is more advantageous in terms of survival to remember threatening stimuli. Stimuli that are low in valence (i.e. unpleasant) and produce high levels of arousal in participants should be recalled more easily than pleasant arousing stimuli.
3. It has been suggested that the degree to which threatening stimuli (i.e. low valence, high arousal) are also unusual or distinctive may determine the degree to which they are remembered. Previous studies have not directly tested the degree to which the distinctiveness of an threatening image improves or impairs memory for that image. It is suggested here that the congruence of a visual and auditory presentation should interact with the valence and arousal ratings assigned to that presentation. Participants viewing ***incongruent*** low valence, high arousal sounds and images should remember more images at later recall than participants shown ***congruent*** combinations of low valence, high arousal images.

5.2. Method

5.2.1. Participants:

An *a-priori* power analysis was conducted (F-tests on means in the ANOVA). A conventionally moderate effect size was chosen (f = 0.60, Alpha = 0.05, power = 0.95) which required a total sample size of 60 participants (12 in each of 5 groups) in order to correctly reject a false null hypothesis [F, (4, 55) = 2.54].

Sixty-five healthy young adults were recruited from a student population at the Universities of St Andrews and Stirling in Scotland [Mean age (SD) 21.19 (5.43)]. These participants were assigned to five experimental groups (information concerning these groups is given below). Details of the demographic composition of the five groups are provided in Table 5.1. Equal numbers of participants were assigned to each of the five groups, however due to anomalies in the recording of physiological responses leading to the exclusion of some participants from analysis and participants withdrawing from the study, two of the five groups consisted of 10 participants each. A third group consisted of 13 participants and the two other groups consisted of 12 participants each (fifty seven participants allocated to five groups). Prospective participants were required to provide either an email address or contact telephone number. Participants were given a choice of reimbursement. They either received credits toward experiment participation records for undergraduate psychology courses or £4 per hour of participation. Participants were not told that the study related to

memory, but rather a range of subjective and physiological reactions were required in response to a set of images and sounds which were, themselves, to be used in future research within the School.

5.2.2. Design:

This study was a mixed factorial design employing five levels of the within- subject variable (emotion category – 1. Low valence, high arousal. 2. Low valence low arousal. 3. Neutral. 4. High valence low arousal and 5. High valence high arousal) and five levels of the between- subject variable (congruence of visual and auditory stimuli – 1. Image alone. 2. Congruent sound and image, 3. Incongruent sound and image. 4. Sound alone (from congruent sound-image pairs – ('c'). 5. Sound alone (from incongruent sound-image pairs – 'I'). Participants were randomly assigned to groups for the between-subject variable but were also assessed for potentially confounding between group variables.

5.2.3. Apparatus and materials:

Participants were required to complete standard self report/check-list measures of intelligence (The National Adult Reading Test – Nelson & Wilson, 1994) and personality (The Eysenck Personality Questionnaire – Revised, Eysenck et al., 1985) on arrival. During testing, in response to visual or auditory stimuli, participants completed an affective rating system for valence (degree of 'pleasantness/unpleasantness') and an affective rating system for arousal called the Self Assessment Manikin (Lang et al., 1999). The self assessment manikin (SAM) used in this study consisted of a graphic figure depicting values along

each of the two dimensions of valence and arousal on a continuously varying scale (for examples of the manikin used in this study see Appendix 6.) The SAM rating system has been extensively used in conjunction with the International Affective Picture System – IAPS that is described below (also see Lang et al., 1999 for published studies using the IAPS system).

Participants were presented with a series of 25 images depicting various scenes, which had been rated in normative studies along valence and arousal dimensions. Each slide was drawn from the International Affective Picture System (IAPS) (Lang et al. 1999. Technical reports A-4, The Center for Research in Psychophysiology, University of Florida). The images were chosen to vary in rated valence and arousal values as determined by normative studies carried out by the authors. Any given image chosen for the present study had received a high, low or neutral valence and arousal rating in the normative procedure. Ratings for arousal and valence ranged from low to high (1 – 9). The distribution of IAPS images in the 'affective space' defined by valence and arousal ratings assigned to them meant that images could not be drawn from equivalent valence and arousal vectors. Five of the 25 images selected for the present study had received low valence (pleasantness) ratings and high arousal ratings (scale = 0-9). Five images were selected for the present study from IAPS images that had received a valence rating of between 1 and 4 and an arousal rating between 5 and 7 in the normative study. (Seven was set as the upper limit for these images and not nine because of the potentially distressing nature of the images rated between 1 and 4 on the valence scale and between 5 and 9 on the arousal scale). These five images constituted the 'low valence high arousal

category' (LVHA). Five of 25 images constituted the 'Low Valence Low Arousal' category (LVLA) and had received valence ratings between 1 and 4 and arousal ratings of between 3 and 5 in the normative study. [Three and five were chosen to represent low arousal instead of 1 and 4 because few items had been collected by the authors that had received arousal ratings between 1 and 4 by the raters (for stimulus set see Appendix 7)]. The five neutral images used in this study received valence ratings between 4 and 6 and arousal ratings of between 3 and 5. High valence low arousal images (HVLA) were drawn from images that had received valence ratings between 6 and 8, arousal ratings between 3 and 5. Finally high valence, high arousal images (HVHA) received valence ratings between 6 and 7 and arousal ratings between 6 and 8. These high arousal-rating parameters were not identical to the high arousal parameters used for the LVHA stimuli (5 – 9). For ethical purposes, selection of images from the valence and arousal ranges in the corpus was not random. Two major themes were excluded. One theme related to sex, the other related to images of the victims of real life homicide/murder, again for ethical reasons only. Only moderately arousing stimuli were used in this study, sufficient to produce a mild emotional response. For a detailed outline of the stimuli in each category see Appendix 7.

In addition to the image stimuli, a series of auditory stimuli were compiled from a range of 'sound effect' CD ranges (available from the BBC). Sounds were copied from these sound effect databases and edited to a length of 10 seconds each. The sound-wave onset time and volume were kept constant for all sounds using sound editing software (Sound Edit™ 1.1 Mac Recorder® Sound System, copyright© 1987-88 Farallon Computing Inc. USA). The sounds used in the present study had not been previously rated in normative procedures

but were selected to match images that had been rated in this way [Since this study, a relatively small corpus of sounds rated on arousal and valence dimensions has been produced (Bradley & Lang 1999b)]. Auditory presentations were either congruent or incongruent to the image presentation. (e.g. an image depicting a barking dog could either be accompanied by a) the sound of a barking dog (congruent) or b) the sound of trotting horses hooves (incongruent)). An operational description of congruence in relation to sound was that the given sound matched the image in a given valence and arousal category. For example, the sound of a barking dog would be deemed 'low valence high arousal' if it matched the low valence high arousal image of a barking dog. Attempts were made to combine sounds and images that were either clearly related to the picture theme or clearly unrelated to the picture theme. An operational description of the procedure used to select an incongruent sound for an image is as follows. An incongruent sound was deemed such if the given sound matched an image in a category that was the opposite of the image with which the sound would be combined as a stimulus. For example, an image of a crying child had received a low valence rating and a high arousal rating by the raters in the normative study (Lang et al 1999). The sound of crying was selected as the congruent sound that clearly related to the picture theme. In order to select an incongruent sound unrelated to the picture theme, a sound was selected that matched the theme of a high valence low arousal image – e.g. a laughing child. The sound of laughing was matched to the high valence low arousal image of a laughing child. The sound of laughing matched a high valence low arousal image and was therefore deemed opposite to the low valence, high arousal image of the crying child in terms of valence and arousal. The combination of an image of a crying child with

the sound of laughing was deemed an incongruent combination for the purposes of this study.

All stimuli (during the presentation and later recognition memory test) were presented on an Apple Macintosh Power Book 3400c 'lap-top' type computer using Superlab Pro software (Cedrus Corporation, 532 E Maryland, Suite B3, Pheonix, AZ 85012. USA). Sound files were edited using SoundEdit software so as to match sound stimulus onset times for the different samples recorded.

5.2.3.1. Five groups of participants were formed based on the combinations of stimuli to be presented :

1. Image alone (IAPS image alone);
2. Sound alone (c) [sounds from congruent sound image pairs – (4)];
3. Sound alone (ic) [sounds from incongruent sound image pairs – (5)];
4. Congruent sound & image [IAPS image and accompanying related (congruent) sound];
5. Incongruent sound & image [IAPS image and accompanying unrelated (incongruent) sound].

See Appendix 7. for further details of the specific stimuli used for each group (N.B. stimulus codes relate to the 1997 IAPS manual – Lang et al., 1997)

The presentation phase consisted of 25 trials of either images or sounds alone or in combination, test consisted of 50 trials of either images or sounds alone or in combination.

During the presentation of 'to be remembered stimuli' the electrocardiogram (ECG) and Galvanic Skin Response (GSR) were continuously recorded using the Biopac Student Lab Pro system (Biopac Systems Inc., Linton Instrumentation, Norfolk) connected to an Apple Macintosh 5300CS-Laptop computer. The GSR and ECG were electronically marked at each stimulus onset and end. Rate information (beats per minute) was calculated from the ECG trace after acquisition for the entire waveform. Heart rate change from baseline and heart rate variation (SD) were analysed for the heart rate data. 'Area under the curve' calculations were made for the galvanic skin response data. The area under the curve calculation uses, as the baseline, a straight line drawn between the two endpoints of a selected area of GSR. The calculation always returns a positive result and the measurement can be considered as the total area between the waveform and the baseline of that waveform (see Busch & Hudson 1996). Obtaining the area under the curve for GSR was considered the most appropriate method for approximation of GSR *responses to presented stimuli* rather than these responses simply *at the time* of stimulus presentation. The use of heart rate change from baseline was considered an appropriate heart rate measure to control for possible differences in individual subject's pre-stimulus value. In addition, the variation in the R-R interval expressed as the standard deviation in heart rate was used as a measure of physiological 'reactivity' to stimuli and has been used as a measure of heart rate variation in previous studies (O'Carroll et al., 1999 a&b).

5.2.4. Procedure:

All prospective participants were contacted by the experimenter and given an information sheet and asked to sign a consent form. Participants were required to complete the self-report measures of intelligence (NART) and personality (EPQ) in order to match groups on these potentially confounding variables, and randomly assigned to one of the 5 groups (see above). None of the participants were told that the study aimed to assess memory, but rather that physiological ratings were required for a new selection of images to use in future research within the department.

- ***Image alone group:*** (10 participants). Baseline ECG and GSR was monitored and recorded during a number of baseline tasks. These included reading sub vocally and vocally and sitting quietly with eyes closed and then open (in that order). Each period of baseline recording (sub-vocal reading, reading out loud, eyes closed and eyes open) lasted for approximately two minutes. Baseline recording was taken over a period of 90 seconds for each baseline period for each subject. Eventual baseline readings were taken from the period during which participants sat quietly with their eyes open, fixating on the blank screen of the computer. These conditions were considered appropriate as an experimental baseline because of their similarity to the experimental task in all aspects apart from the presentation of the to-be-remembered stimuli. During the image presentation, participants viewed 25 images for 10 seconds each. After each image they had approximately 30 seconds to complete a visual analogue 0-9 (SAM) rating of how aroused and how pleasant they felt when viewing the image. After a one-week interval, participants were required to return to "rate another set of slides" however on

arrival they were assessed on a free recall memory task for images presented one-week earlier. They were then presented with 50 image presentations (25 of which they had been shown before). Participants were required to state either yes or no to the question "have you seen this slide before" and reaction times were recorded. The order of presentation of the stimuli was automatically randomised for each subject by the experimental software (Superlab).

- ***Congruent group:*** (10 participants). The procedure for this group was identical to that for image alone group. However, images at presentation were accompanied by auditory stimuli appropriate to the image. Participants were required to rate the slides using the SAM. At test all 10 participants were required to freely recall images. In addition, response latencies were measured during the presentation of the slide and sound together.
- ***Incongruent group:*** (13 participants). The procedure for this group was identical to that for the image alone group. However, images at presentation were accompanied by auditory stimuli ***inappropriate*** to the image. Again, participants were required to rate the slides using the SAM. The test procedure was identical to the congruent group.
- ***Sound alone (c):*** 12 participants. The procedure for this group was identical to that for image alone group. Participants were however required to rate and respond to sounds only at presentation and test. These sounds were identical to those that accompanied IAPS images in the congruent group (i.e. the sounds that matched the images). At one-week interval, participants were required to return to "rate another set of sounds" however on arrival they were assessed on a free recall memory task for sounds presented one-week

earlier. They were then presented with 50 sound presentations (25 of which they had heard before). Participants were required to state either yes or no to the question "have you heard this sound before" and reaction times were recorded. The order of presentation of the stimuli was automatically randomised for each subject by the experimental software (Superlab).

- ***Sound alone group (ic):*** 12 participants: The procedure for this group was identical to that for slide alone group. Participants were however required to rate and respond to sounds only at presentation and test. These sounds were identical to those that accompanied IAPS images in the incongruent group (i.e. the sounds that were inappropriate to the images). The one-week memory test for this group was equivalent to the sound alone (c) group (see above).

5.2.5. Analysis:

One-Way Analysis of Variance (ANOVA) was employed to assess possible between group differences in potentially confounding variables and in total free recall memory scores and recognition memory scores. Repeated measures ANOVA was used to assess effect of group (1-5), category (LVHA; LVLA; N; HVLA; HVHA) and interactions between group and category on subjective self- ratings of valence and arousal in response to the presentation. The same repeated measures analysis was employed for the physiological responses at the time of presentation of the stimulus materials and for recall and recognition memory performance at one- week interval.

As in the previous chapter, the within-participants variable had more than two levels and accordingly, Mauchly's test of Sphericity was conducted on the within-subject variable. The significance of Mauchly's W would indicate that the assumption of equivalent correlations between the variables in the ANOVA was not supported. In the event of this analysis being significant, and according to current convention (Brace et al., 2000, p192), a multivariate criterion of Wilks' Lambda would be adopted for the within-subject factor in the analysis. In the event of this analysis being non-significant, then the univariate results would be reported.

Planned post hoc comparisons were conducted using Post Hoc LSD (for the between- group variable) and paired t-tests for within group variables. In the event of the between-group variable being non-significant, t-tests were carried out on the entire sample.

5.3. Results

5.3.1. Potentially confounding between- group variables

The five groups in this study (image alone group 1; sound alone (c) group 2; congruent image/sound group 3; incongruent image/sound group 4 and sound alone (ic) group 5) were well matched on potentially confounding variables. These included age, year of study at university, IQ as expressed by their error score on the NART, and the personality variables of extroversion, neuroticism

and psychoticism as measured by the EPQ (see Table 5.1). In addition, there were no significant differences between groups on baseline heart rate or galvanic skin response collected before the stimulus presentation. The standard deviations of heart rate and galvanic skin responses during baseline were also not significantly different between groups (see Table 5.1.).

Table 5.1: Participants matched on potentially confounding variables (cells are means and standard deviations)

Potential confound	Group 1 Image alone N = 10	Group 2 Congruent sound alone N = 12	Group 3 Congruent sound and image N = 10	Group 4 Incongruent sound and images N = 13	Group 5 Incongruent sound alone N = 12	F	P
Age	25.6 (11.29)	19.4 (1.16)	20.6 (3.81)	20.2 (2.42)	20.8 (1.9)	2.31	.07
Sex	M=5,F=5	M=3,F=9	M=5,F=5	M=6,F=7	M=3,F=9	χ^2=3.88	.51
Study year	2.11 (1.45)	2 (1.21)	2 (1.41)	2.46 (1.45)	2.58 (1.31)	.47	.76
Nart error	15.40 (6.02)	18.08 (5.57)	16.6 (5.51)	17.92 (5.94)	18.67 (5.89)	.56	.70
EPQ: E	8.3 (2.67)	8.42 (1.93)	9.00 (2.75)	7.85 (3.51)	8.00 (2.17)	.31	.87
EPQ:N	5.00 (4.08)	6.42 (2.71)	5.90 (3.73)	4.85 (3.18)	6.83 (2.59)	.84	.51
EPQ:P	3.2 (1.69)	3.33 (2.19)	3.40 (2.68)	3.46 (2.60)	3.25 (2.96)	.02	1.00
EPQ:L	3.1 (2.38)	1.33 (1.37)	2.50 (2.27)	2.62 (1.76)	1.92 (1.68)	1.47	.23
GSR Base	21.33 (7.21)	22.70 (10.44)	25.81 (11.02)	22.59 (9.45)	22.32 (8.32)	.33	.86
GSR SD	.77 (364)	.49 (.23)	.77 (.50)	.64 (.42)	.56 (.46)	.78	.55
ECG Base	85.20 (8.78)	77.31 (6.8)	77.01 (9.76)	75.84 (7.86)	74.66 (7.38)	1.91	.13
ECG SD	5.10 (2.53)	4.66 (1.67)	6.14 (3.17)	4.74 (2.03)	6.44 (.93)	1.75	.17

Key: EPQ: Eysenck Personality Questionairre – Revised (Eysenck, 1985). E: Extroversion score. N: Neuroticism score. P: Psychoticism score. L: Lie score. GSR: Galvanic Skin Response (micro mho). Base: Baseline. SD: Standard deviation. ECG: Electrocardiogram (bpm)

5.3.2. Physiological and subjective responses at presentation:

5.3.2.1. Subjective responses

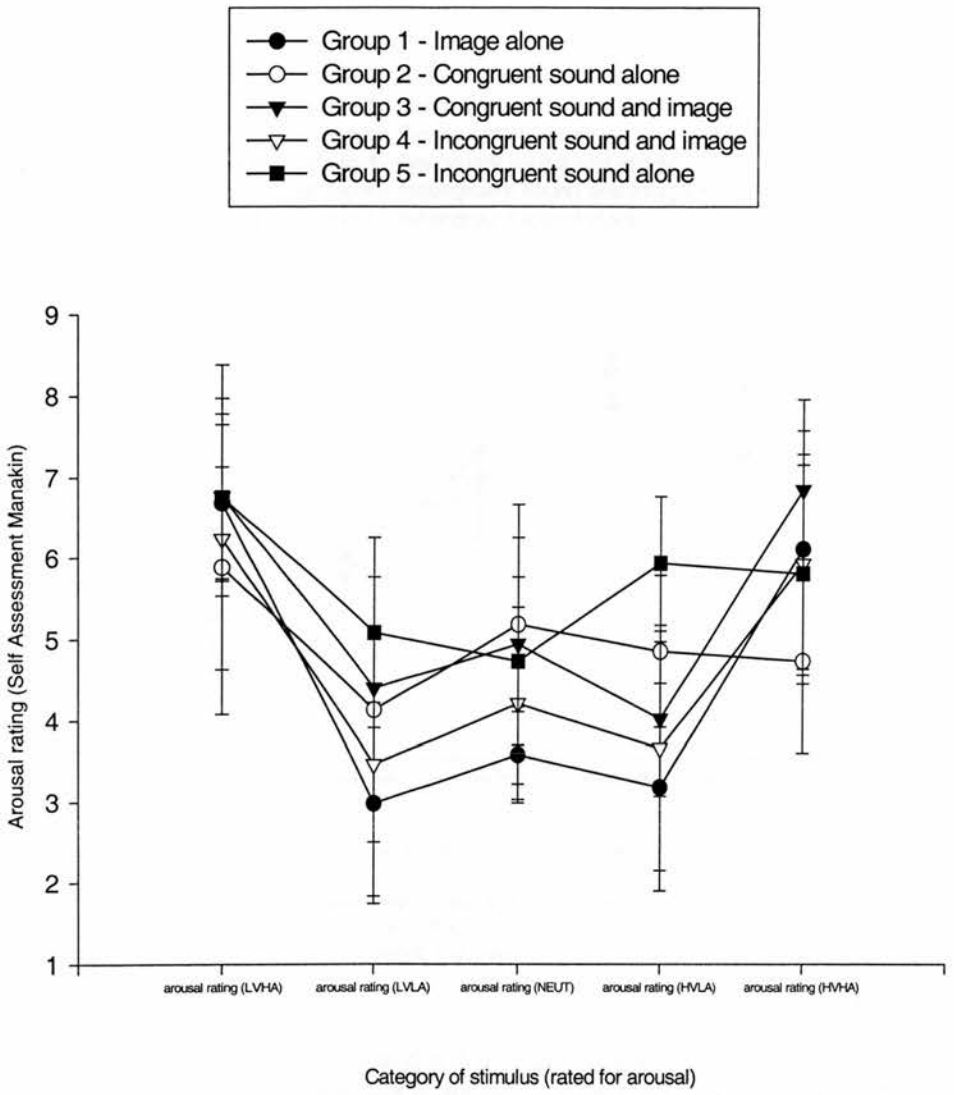
Participants in this study produced the expected pattern of valence and arousal SAM self-ratings to the five constructed stimulus categories (LVHA, LVLA, N, HVLA, HVHA – see Figures 5.1 and 5.2). Mauchly's test of Sphericity was not significant for the within- group variable of arousal rating [W (9) = .74, p = .08] and therefore, univariate results are reported. For self- ratings of arousal, repeated measures ANOVA revealed no significant effect of group [F (4, 52) = 2.24, p = .06], a significant effect of category [F (4, 208) =, 81.59, p = .01] and a significant category by group interaction [F (16, 208) = 6.57, p = .01]. The ratings of arousal made to the low valence (unpleasant), highly arousing category of stimuli was significantly greater than all other category ratings (see Figure 5.1). The ratings of other categories included the ratings of arousal made to the low valence, low arousal stimulus category [i.e. LVHA vs. LVLA: t (56) = 12.28, p = .01], the neutral category of stimuli [LVHA vs. N: t (56) = 10.49, p = .01], the high valence, low arousal category of stimuli [LVHA vs. HVLA: t (56) = 8.86, p = .01] and the high valence, high arousal category of stimuli [LVHA vs. HVHA: t (56) = 3.01, p = .01]. The greater level of arousal ratings assigned to the unpleasant, high arousal category of stimuli occurred in all 5 groups to an equivalent degree (see Appendix 8. for values relating to the interaction).

When participants rated the stimulus categories in terms of valence (pleasantness) (see Figure 5.2), high ratings of valence were assigned to 'high valence' categories and lower ratings of valence to 'low valence' categories. Mauchly's test of Sphericity was significant for the within group variable of valence rating [W (9) = .74, p = .01] and therefore, the multivariate criterion of

Wilks' Lambda was used to test the effect of category. There was no significant effect of group [F (4, 52) = 2.02, p = .10], a significant effect of category [F (4, 49) = 87.94, p = .01] and a significant category by group interaction [F (16, 208) = 8.47, p = .01] – See Figure 5.2. Participants produced greater ratings of valence to high valence categories than low valence categories [t (56) = -9.41, p = .01]. (see Appendix 9. For post hoc LSD relating to the interaction).

To summarize the analysis of the subjective ratings, subject ratings of valence seemed to mirror the ratings of valence expressed in each category name so that categories containing 'pleasant' stimuli received higher ratings of valence than did categories containing unpleasant stimuli. Subject ratings of arousal on the other hand deviated slightly from the arousal ratings assigned in the IAPS normative study. Participants rated the unpleasant high arousal category as being more arousing than all other categories – including the category that contained pleasant high arousal stimuli.

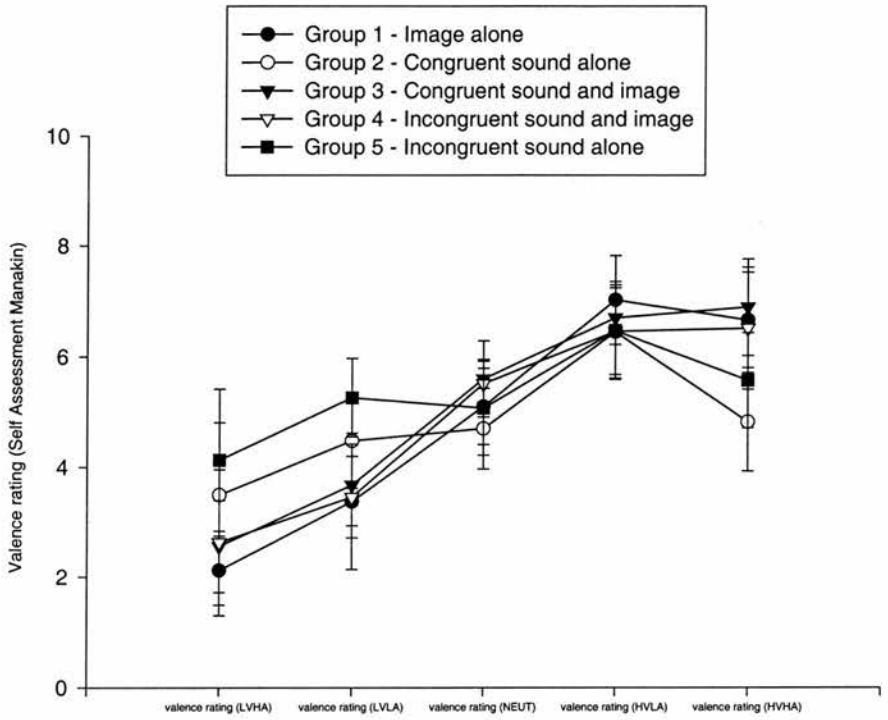
Figure 5.1. Subjective Ratings of Arousal to Stimulus Categories by Group



LVHA: Low valence high arousal. **LVLA**: Low valence low arousal **NEUT**: Neutral, **HVLA**: High valence low arousal, **HVHA**: High valence high

[Significant effect of category and a significant category by group interaction LVHA arousal ratings > LVHA, NEUT, HVLA & HVHA arousal ratings. For interaction see Appendix 8.]

Figure 5.2. Subjective Ratings of Valence to Stimulus Categories by Group



LVHA: Low valence high arousal. **LVLA**: Low valence low arousal
NEUT: Neutral, **HVLA**: High valence low arousal,
HVHA: High valence high

[A significant effect of category and a significant category by group interaction. High valence ratings > Low valence ratings. For the interaction see Appendix 9.]

5.3.2.2. Physiological responses

The 'area under the curve' calculation of galvanic skin response was considered the most reliable indicator of arousal *in response* to stimulus presentation as opposed to arousal *at the time* of stimulus presentation. Analysis of variance on area under the curve results in response to the five stimulus categories by group is displayed in Figure 5.3. Mauchly's test of Sphericity was significant for the within group variable of category of image [W (9) = .69, p = .02] and therefore, the multivariate criterion of Wilks Lambda was employed. The analysis revealed no significant effect of group [F (4, 52) = .47, p = .76] and a significant effect of category [F (4, 49) = 5.64, p = .01]. Treating the sample as a whole, unpleasant highly arousing stimuli (LVHA) produced greater GSR area under the curve values than Low valence low arousal stimuli [t (56) = 3.59, p = .01], neutral stimuli [t (56) = 3.81, p = .01], high valence low arousal stimuli [t (56) = 2.87, p = .01] and high valence high arousal stimuli [t (56) = 2.86, p = .01 - see Figure 5.3]. However, there was a significant group by category interaction [F (16, 208) = 1.74, p = .04] such that the group viewing congruent combinations of sounds and images produced greater area under the curve values for unpleasant and highly arousing images than the image alone group, the congruent sound alone group and the incongruent sound alone group [Post hoc LSD: Grp 3 > 1 (p = .01), 2 & 5 (p = .04)], but not the critical comparison of interest (congruent sound and image versus incongruent sound and image).

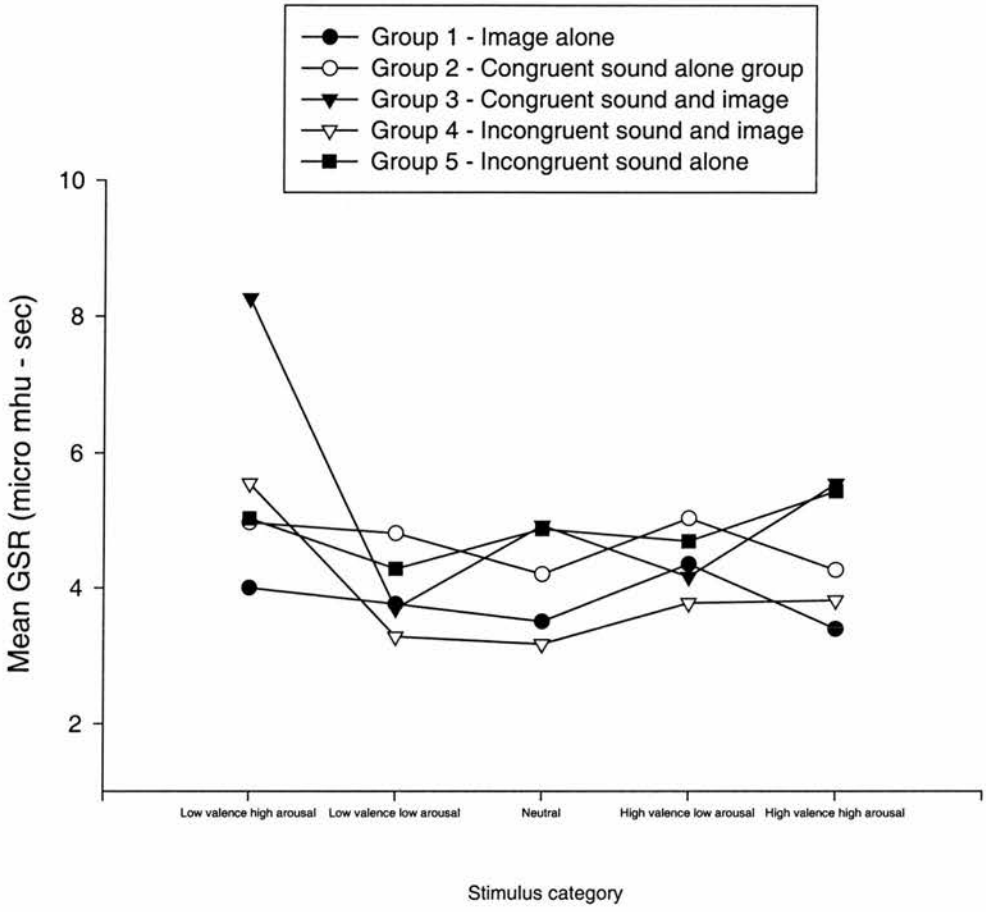
In addition to GSR area under the curve values, two measures of heart rate were analyzed. The first of these measures was mean heart rate change from baseline. Mauchly's test of Sphericity was significant for the within-group variable of category of image [W (9) = .371, p = .01] and accordingly the

multivariate criterion of Wilks' Lambda was used to test this variable. The analysis revealed no significant effect of group [F (4, 43) = 1.12, p = .36] no significant category by group interaction [F (16, 123) = 1.49, p = .12] and an effect of category that was borderline significant [F (4, 40) = 2.66, p = .05]. The trend across all participants was to produce mean heart rate *reductions* relative to baseline during stimulus presentation. Participants, regardless of group, produced smaller heart rate reductions from baseline values when presented with the high valence, high arousal category of stimuli than either the low valence, high arousal category [t (47) = -2.72, p = .01.] or the high valence, low arousal category of stimuli [t (48) = -3.14, p = .01]. All other post hoc comparisons were non-significant. In addition to heart rate change from baseline values in response to stimuli at encoding, the variation of heart rate during stimulus presentation was deemed the most appropriate indicator of heart rate in response to stimulus presentation. Heart rate variation was represented by the standard deviation from the mean heart rate during the time the stimulus was presented. An analysis of heart rate fluctuation to stimulus categories by group is displayed in Figure 5.4. Mauchly's test of Sphericity was significant for the within-group variable of category of image [W (9) = .09, p = .01] and therefore, the multivariate criterion of Wilks' Lambda was used to test this variable. The analysis revealed no significant effect of group [F (4,44) = 2.54, p = .05], no significant effect of category [F (4, 41) = .37, p = .83], and no significant category by group interaction [F (16, 176) = .79, p = .70].

To summarize the physiological responses to stimuli presented in this study, all participants' heart rate decelerated during stimulus presentation compared to baseline heart rate. Participants' mean heart rate change from

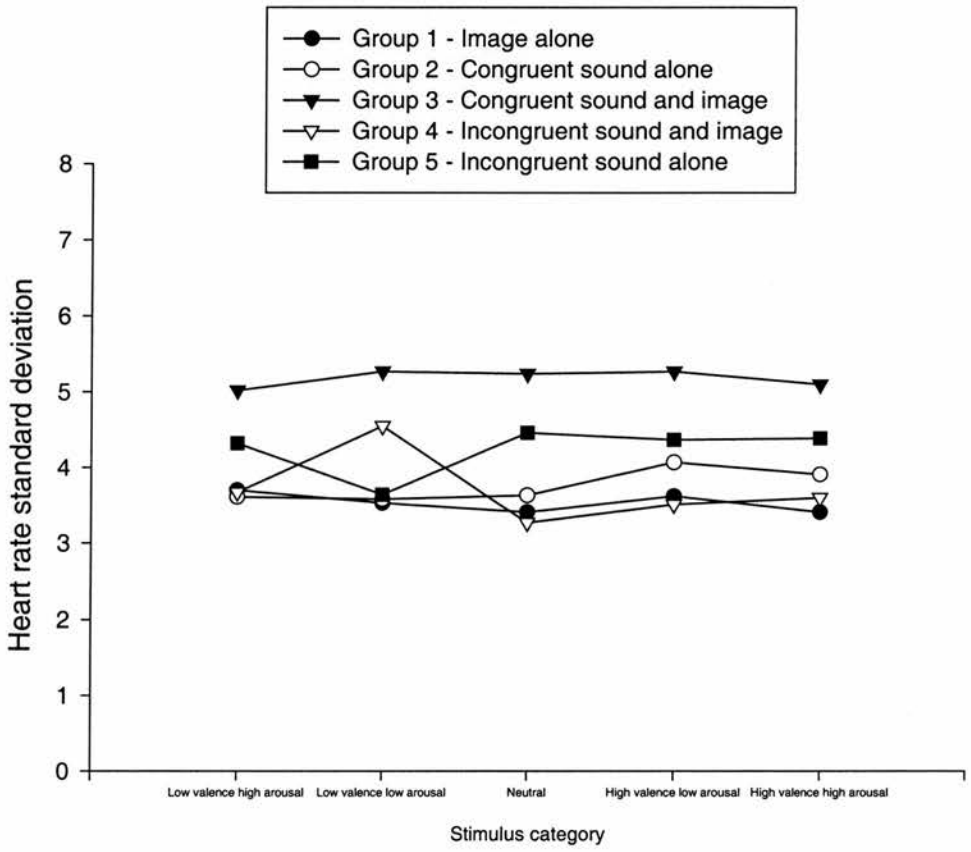
baseline fluctuated from baseline *least* in response to the high valence, high arousal category of stimuli. Participants' heart rate variation in response to the stimuli did not differ between groups or in response to the different categories of stimuli (Figure 5.4). However, participants' GSR responses were greater for unpleasant (low valence) highly arousing images as compared to all other categories, including pleasant (high valence) highly arousing images. This effect was most apparent in the group of participants looking at unpleasant, highly arousing images with matching (congruent) sounds (Figure 5.3).

Figure 5.3. Area Under the Curve of the Galvanic Skin Response for 5 groups to 5 Stimulus Categories



[Significant effect of category: LVHA > LVLA, NEUT, HVLA, HVHA and a significant category by group interaction: In the LVHA category, Group 3 > 1, 2 & 5]

Figure 5.4. Heart Rate Variability to Stimulus Categories by Group



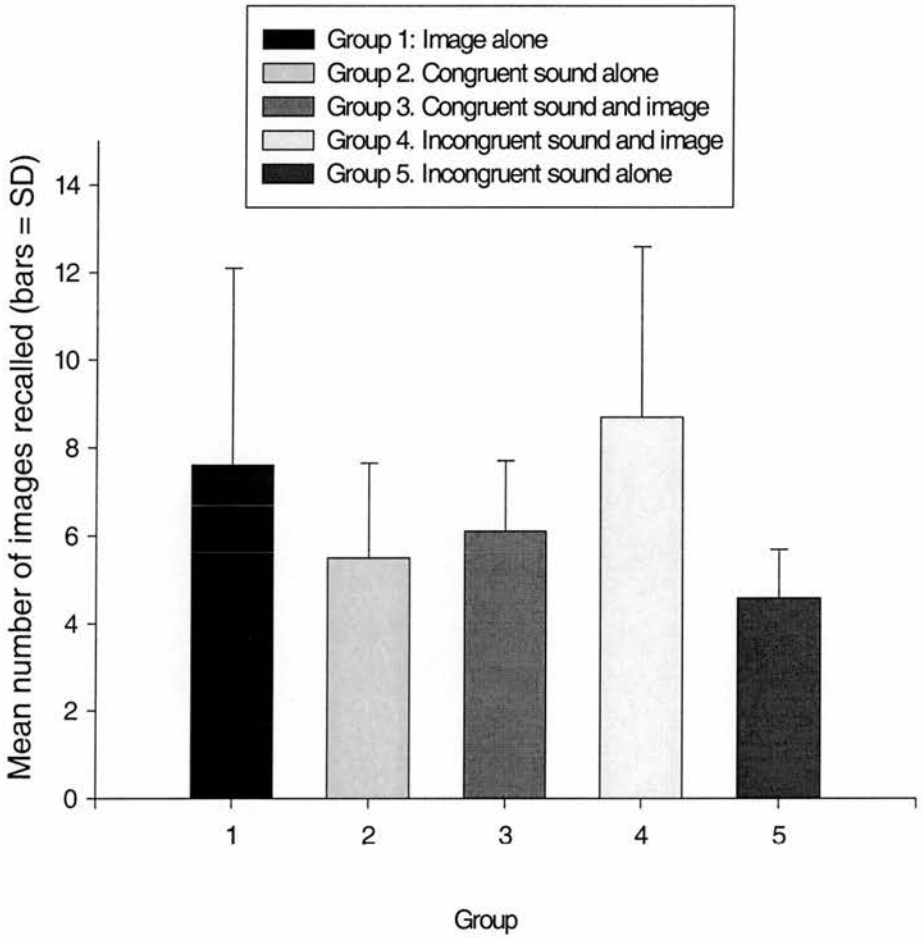
[No significant effects or interactions]

5.3.3. Memory Performance

One-week following stimulus presentation, all participants, regardless of group returned to the laboratory and received a 'surprise' memory test consisting of two components: a free-recall memory test and a forced-choice reaction-time recognition memory test for the stimuli presented one-week previously.

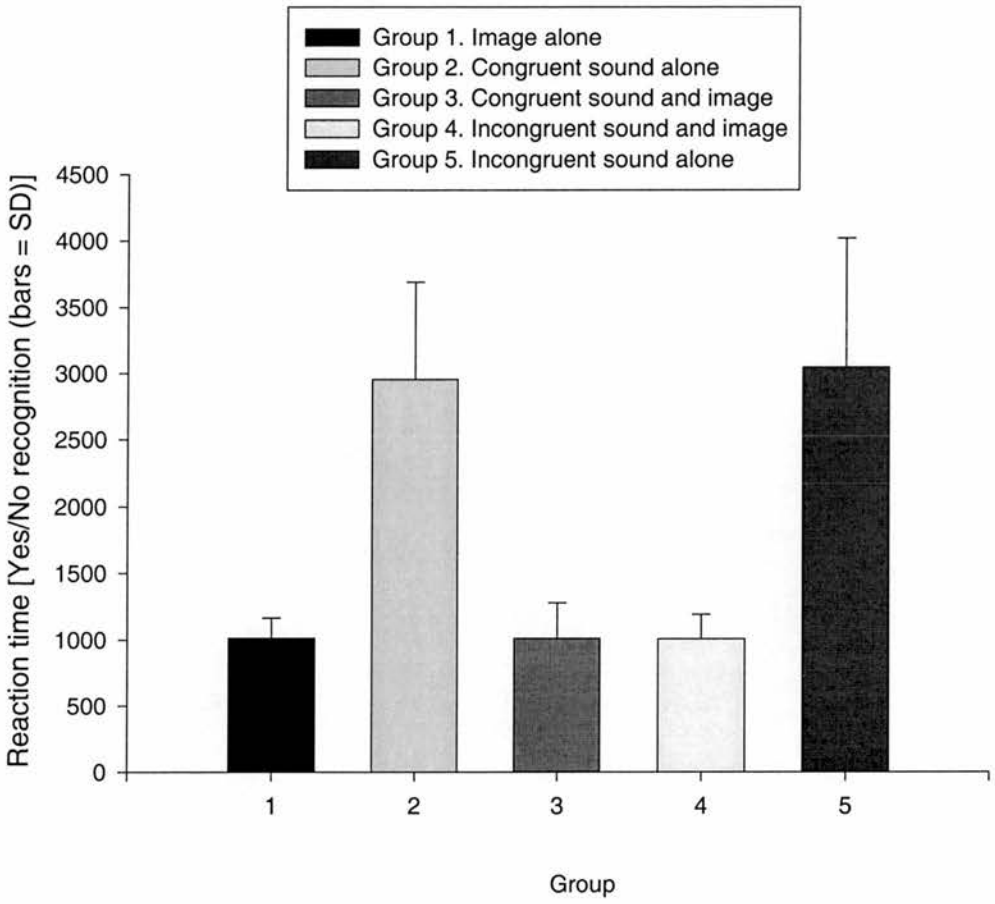
There were significant differences between groups of participants in terms of the total number of slides/sounds recalled in the free recall test [$F(4,56) = 3.74$, $p = .01$] – See Figure. 5.5. Critically, participants presented with incongruent combinations of images and sounds remembered significantly more of the images presented a week previously than did participants who were presented with congruent combinations of images and sounds [Post hoc. $p = .04$]. Furthermore the incongruent sound and image group recalled more images than the congruent sound alone group [$p = .01$] and the image alone group remembered more images than the incongruent sound alone group remembered sounds [$p = .01$].

Figure 5.5. Total Recall Memory by Group



[Significant between-group effect - Group 4 > 3, 2 and 5]

Figure 5.6. Recognition Memory (Reaction Time) by Group



[Significant between-group effect - Group 2 > 1, 3 and 4.
Group 5 > 1, 3 and 4]

The recognition memory performance was at ceiling for the 5 different groups. However, an analysis of the time between target or distracter stimulus onset and correct response (reaction times) of the different groups revealed a significant between- group effect [F (4, 54) = 40.46, p = .01] – see Figure 5.6. Participants who heard sounds alone at presentation (be they the sounds that were incongruently or congruently combined with images in the other groups) took significantly longer to respond correctly than participants who viewed images alone or images and sounds that were in congruent or incongruent combinations. [Post hoc LSD, sound alone (c) > image alone, congruent sound and image and incongruent sound and image (p = .01). Sound alone (ic) > image alone, congruent sound and image, and incongruent sound and image (p = .01)].

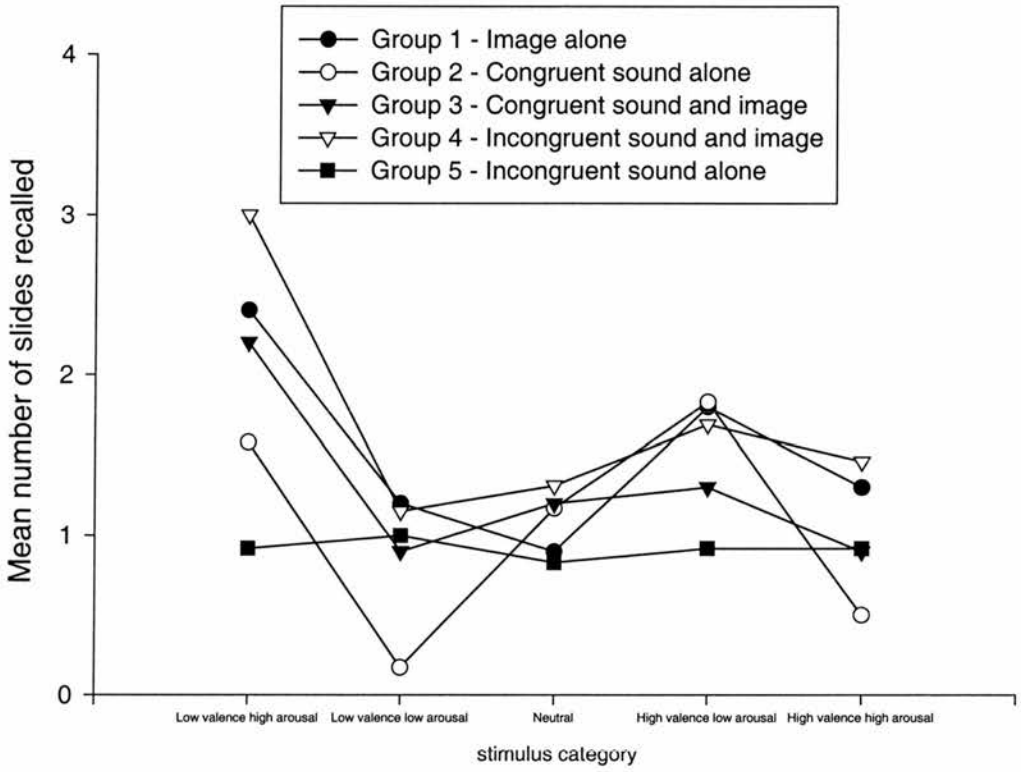
Analysis of free-recall memory performance for the different categories of stimuli by group was conducted. Mauchly's test of Sphericity was significant for the within-group variable of category of image [W (9) = .58, p = .01] and therefore the multivariate criterion of Wilks Lambda was used to test this variable. Analysis indicated a significant effect of category [F (4, 49) = 10.58, p = .01], a significant effect of group [F (4,52) = 3.94, p = .01] and a significant category by group interaction – [F (16, 208) = 2.41, p = .02] (see Figure 5.7). The low valence highly arousing category of stimuli was remembered better than all other categories [LVHA > LVLA, t (56) = 5.58, p = .01. LVHA > N, t (56) = 5.37, p = .01. LVHA > HVLA, t (56) = 3.03, p = .01 and LVHA > HVHA, t (56)

= 5.34, p = .01]. In addition, a one –way ANOVA conducted to investigate the significant interaction indicated that participants who had been presented with incongruent combinations of sound and images recalled more images in the low valence high arousal category than either the congruent or incongruent sound alone groups recalled sounds: [F (4,56) = 8.12, p = .01. Post hoc LSD = incongruent sound and image - Grp 4. > sound alone (c) – Grp 2. & sound alone (ic) – Grp 5., p = .01]. In addition, the image alone group and the congruent sound and image group remembered more low valence high arousal images than the incongruent sound alone group remembered sounds [F (4, 56) = 8.12, p = .01. Post Hoc LSD = image alone and congruent sound and image > sound alone (ic) (p = .01)]. However, there was no significant difference between the congruent and incongruent group.

To summarize the memory results, overall, participants who were presented with incongruent sounds and images remembered most images in free recall one-week later (irrespective of category) and more than participants who had been presented with the same images with congruent sounds (Figure 5.5). Reaction times to the stimuli when they were presented again in the second session were longer for the participants who only heard sounds, and it made no difference to reaction times if a subject had viewed an image by itself or in congruent or incongruent combination with a sound (Figure 5.6). Participants remembered more slides from the unpleasant arousing category than any other, and participants who had low valence and highly arousing images in combination with incongruent sounds performed best in terms of the number of images they recalled. However, the incongruent group was not significantly

different from the congruent group in this, the low valence, and high arousal category (Figure 5.7).

Figure 5.7. Free recall memory performance for categories by group.



[Significant effect of category (LVHA > LVLA, N, HVLA, HVHA).
Significant effect of group and a significant category by group interaction]

5.4. Discussion

5.4.1. Subjective reactions to stimuli

Participants in this study were randomly assigned to groups for the between-subject variable of congruence but were also matched closely on potentially confounding variables like age, sex, IQ, personality and the baseline physiological responses of heart rate and galvanic skin response (GSR). Subsequent differences between groups cannot therefore be attributable to these potential between group confounds. Participants, regardless of group, produced the expected patterns of subjective self-ratings for both valence and arousal using the SAM to each of the different categories of stimuli. For example, all participants produced high ratings of arousal (Figure 5.1.) and low ratings of valence (Figure 3.2) to the high arousal low valence category of stimuli. This indicates that participants in this study were using the Manikin and rating the images in a similar way to the participants in the normative study (Lang et al 1997). It also indicates that the categories in this study, constructed on the basis of the arousal and valence ratings of the normative group were rated similarly by the participants in this study. Within-participants, there was a significant effect of category of stimuli in terms of the SAM arousal ratings made to the low valence high arousal images (the unpleasant high arousal images). All participants produced higher arousal ratings for the unpleasant and highly arousing stimuli.

5.4.2. Does arousal predict memory?

It has been suggested that categorical and dimensional approaches to the classification of emotion in relation to memory would predict different outcomes in this study. A dimensional approach would argue that although participants encode 'to be remembered' stimuli in terms of the dimensions of both valence and arousal, it is the level of arousal that is more predictive of later recall than the level of valence (Bradley et al 1992; Hamann et al., 1999). This approach would predict that participants who rated stimuli as being high in arousal would be more likely to remember them regardless of the level of associated valence. In other words, there should be no difference between the number of unpleasant highly arousing pictures recalled and the number of pleasant highly arousing pictures recalled. Clearly this was not the case in the present study. All participants remembered more of the low valence, high arousal images than the high valence high arousal images and all other categories (see Figure 5.7). It is possible to suggest, on the basis of the results of this study, and contrary to Bradley et al (1992) that high arousal alone does not predict better recall, rather the specific interaction of high arousal and low valence is associated with better long- term (1-week) recall. The categories in this study are not the categories used in general parlance (fear, anger, disgust etc) or in other studies supporting category effects in memory (Calder et al., 1996). Nevertheless, 'emotion' combinations in relation to images were formed in this study, which relate broadly to the categories used in everyday parlance. It is reasonable to suggest that the emotion categories of 'fear' and 'anger' could be described as 'low valence and high arousal' for example. This study has demonstrated that both

valence and arousal dimensions, when differentially combined to form categories produce reliable differences in human memory that are not observed with single dimensions.

That high arousal alone is not predictive of later memory performance makes 'evolutionary' sense. In terms of survival, it does not pay for an organism to remember all highly arousing stimuli equally well. For example the physiological arousal elicited by the sight and odour of a predator while drinking may be similar perhaps to the arousal elicited by sibling play in certain species. Both behaviors may elicit arousal. However one behaviour has a higher survival probability than the other. Measurement of both perceived levels of arousal and valence in studies of human memory are required before conclusions can be drawn about the best way to understand the organization of memory for arousing material.

5.4.3. Subjective versus physiological arousal: which predicted memory?

The between-group pattern of *physiological* responses at presentation differed from the between-group pattern of *subjective* ratings at presentation. The area under the curve of the galvanic skin response for all participants indicted that for all categories, apart from the low valence, high arousal category, physiological responses were similar both between categories and between groups (see Figure 5.3). However, there was a significant group by category interaction in the absence of a significant effect of group. This revealed that while all other categories produced no significant between group differences in terms of GSR, there were significant between-group differences in response to

the low valence, high arousal presentation. Group 3, the group presented with congruent sound and image presentations, produced significantly greater GSR responses than both the sound alone groups (c and ic) and the image alone group (see Figure 5.3.). On the basis of participants' GSR and subjective responses to stimuli in this study, it appears that the combination of low valence, high arousal images presented with congruent sound result in participants producing greater GSR values to those presentations. This indicates that the presentations were more physiologically arousing than if the unpleasant images were presented alone or if the sounds (either congruent or incongruent) were presented alone. The GSR response was still greater to the low valence, high arousal category as compared to all others for all participants. It was predicted that the incongruent low valence high arousal stimuli would elicit the greatest physiological responses. However, contrary to prediction, the observed GSR responses to the unpleasant and arousing presentations was greatest for the congruent group in the low valence, high arousal category. If physiological response predicts subsequent memory, it would therefore have been reasonable to predict that participants in the congruent group would produce better memory scores for this unpleasant category of stimuli.

However, it transpired that memory performance was more closely associated with the *subjective ratings* of the categories given by the different groups rather than the physiological responses of the different groups. The overall number of images remembered 7 days after presentation was significantly greater for images rated as low valence, high arousal than any other category (see Figure 5.7). Similarly, participants produced the highest self-ratings of arousal at presentation to low valence, high arousal images. (See Figure 5.1.)

5.4.4. Incongruent versus congruent stimuli: which combination predicted memory?

When analysing the between-group memory performance across all valence and arousal categories, images that were accompanied by incongruent sounds were significantly better remembered at the surprise 7 day free-recall assessment than images that were accompanied by congruent sounds (see Figure 5.5).

The prediction made in the introduction of this chapter was that the memory advantage for incongruent combinations of sounds and images should be most pronounced under conditions of threat (i.e. low valence and high arousal conditions). However, when analysed by emotion category, there were no significant differences between the memory performance of participants who saw incongruent combinations of images and sounds and participants who saw congruent combinations of images and sounds.

This finding, although contrary to the initial predictions, can be taken as evidence to partially support the claim that unusualness (or in this case 'incongruence') cannot explain the emotional memory effect seen in many studies. Christianson and Loftus (1991) found that participants viewing closely matched unusual images did not show a memory advantage for central detail information when memory was tested later (unusual condition). By contrast, participants viewing an emotional image did show a memory advantage for the central detail (emotional condition). In the current study, attempts were made to compare memory performance, not for closely matched images, but for *identical*

images under conditions of either 'congruence' (i.e. usualness) or incongruence (i.e. unusualness). The current study has found that memory for threatening or unpleasant stimuli (i.e. low valence, high arousal stimuli) is superior to memory for all other categories of emotion assessed. However, the degree to which the stimulus is congruent or incongruent does not translate into significant differences in memory when comparing the effects of congruence within categories. In other words, when we have an emotional reaction to a given stimulus, self- rated emotional reactions to the stimulus predicts memory, over and above the 'unusualness', 'incongruence' or 'distinctiveness' of the stimuli.

This does not necessarily preclude 'unusualness' in the process of emotional responses to stimuli that lead to superior recall for those stimuli. It is more plausible perhaps that the unusualness of a given stimulus, or rather the degree to which a stimulus is congruent or incongruent with a given context, predicts the onset of an emotional response to that stimulus. For example we are more likely perhaps to have a 'full blown' emotional reaction to the sight of a dangerous animal if we come across it unexpectedly in the wild than if we come across it in a zoo. However, the results of the current study imply that once initiated, it is the subjective emotional reaction to a given stimulus, specifically a classification as unpleasant and arousing, that predicts the degree to which it will be remembered and not the degree to which the stimulus is congruent or incongruent with a given context. There was no difference in terms of memory performance if the unpleasant and highly arousing visual image was either incongruent or congruent with other stimuli presented at the same time.

5.4.5. The 'control' groups – Images presented alone and sounds presented alone

Participants in the sound alone groups were significantly slower to respond than image alone groups and the two groups who were presented with sound/image combinations to correctly recognize a sound as familiar. Being shown an image alone or being shown an image and sound in either congruent or incongruent combination made no difference to the speed at which participants rated a presentation as being familiar. Sound onset time was equated between categories and general stimulus onset time was equated between all groups, so it is unlikely that participants were slower to recognize sounds because of idiosyncratic stimulus properties. However, it should be noted that the sounds in this study were chosen to match visual stimuli that represented different pictorial events. The sound stimuli were more complex sound effects representing the images with which they were associated (e.g. the sound of a dog barking or the sound of a microwave etc). The lack of significant differences in terms of the ratings of these sounds compared to the ratings assigned to the images included in normative studies indicates that attempts to match images and sounds in terms of valence and arousal were successful. Participants rated these 'sound alone' presentations according to category. For example, a high arousal category sound would be generally rated as being more arousing to a subject than a low arousal category sound although this became blurred between the categories of high valence, high arousal and high valence low arousal. It is more parsimonious to suggest that sound rating and recognition is a more complicated task for participants in this study than visual image rating and recognition.

5.4.6. Cautionary notes:

This study employed a series of auditory stimuli from a series of sound effect databases. However, a corpus of sounds rated in terms of valence, arousal and dominance has since been produced by Bradley and Lang (1999b) called the International Affective Digitalized Sounds (IADS). Attempts to formulate congruent and incongruent sound image presentations in this study relied on matching non-rated sounds with rated images in order to gain some indication of the valence and arousal value of sound. The results of this study indicate that participants rated sounds collected in the predicted direction in terms of valence and arousal. However, future research should benefit from a rated normative sample of sounds. However, the IADS contains a limited number and range of sounds at present.

The stimulus materials used in this study were not like stimuli employed in studies of visual perception and recognition in that they were complex representations of events that occur in everyday life. Categorisations were made based on the normative valence and arousal ratings made by participants in the USA (Lang et al., 1999). It is possible that cross-cultural differences exist between the subjective reactions exhibited to the stimulus materials in Scotland and in Florida. In addition, it is possible, that due to the complexity of these images, differences in memory performance may be associated with some aspect of the presentations other that rated valence and arousal (e.g. complexity, lighting, semantic category differences in content etc). Although attempts were

made to select images at random from the parameters set out in section 5.2.3, these possibilities have not been ruled out in the current study and conclusions drawn are limited to those relating to memory performance in relation to valence and arousal ratings only.

5.4.7 Conclusion

This study has demonstrated that, in general, incongruent combinations of sounds and images presented to human participants are better recalled than congruent combinations of sounds and images. It has also demonstrated that arousal alone in response to stimuli does not always translate into improved memory performance, but rather it is the interaction of an image in terms of both self-rated arousal (high) and valence (low) that determines subsequent memory performance. Critically however, when an image sound presentation was rated as low in valence (unpleasant) and high in arousal, it made no difference if the combination of sound and image was congruent or incongruent. It is possible to speculate that this critical interaction between low valence and high arousal overrides any effect of congruence /incongruence on memory. The finding indicates that self-ratings of valence and arousal (i.e. emotional reactions) in response to specific stimuli rather than the congruence of a specific stimulus are the best predictors of memory performance.

Chapter Six.

The human amygdala and emotional memory: Laterality effects.

6.1. Introduction

6.1.1. Studies of the healthy human amygdala

Studies of amygdala function in humans have involved attempts to associate metabolic changes in different brain structures with memory performance in healthy adults. Studies have also assessed memory functioning in patients who, due to surgical intervention or disease have selective damage to the amygdala. Cahill and colleagues (1996) used positron emission tomography of cerebral glucose metabolism in healthy adults to investigate the relationship between amygdala activation and long-term declarative memory for emotional material. In a within participants design, participants were shown two videos during PET scanning. These sessions were separated by 3 – 7 days. The emotional video consisted of 12 emotionally arousing film clips while the neutral video consisted of 12 relatively neutral film clips. Three weeks following the second video session, free-recall

memory performance in the participants was assessed over the telephone. At presentation, participants produced higher emotional reactions to the emotional film clips, as compared to the neutral clips, and participants recalled significantly more of the emotional film clips than the neutral film clips after 3 weeks. The glucose metabolic rate of the right amygdaloid complex (AC) while the films were being presented was significantly positively correlated, and predicted the number of emotional film clips recalled after the three-week interval. AC activity was not correlated with the number of neutral film clips recalled at the three-week interval. These results were interpreted by the authors as providing evidence that the AC is selectively involved with formation of enhanced long- term recall for emotional material. The study reported a relationship between right amygdala activation and long-term, episodic emotional memory performance. Similar findings have been reported by other researchers (e.g. Rauch et al., 1996) while aversive classical conditioning paradigms during PET scanning have not demonstrated amygdala activity (Hugdahl et al., 1995). Specifically, Rauch et al (1996) exposed 8 Post Traumatic Stress Disorder patients to audio taped traumatic and neutral scripts. This study suggests that the processing of 'traumatic' audio taped sequences in PTSD involves activation of structures such as the amygdala, specifically in the right hemisphere. Increases in blood flow were found for the traumatic as compared to the control conditions in right-sided limbic, para limbic and visual areas. It is not unreasonable to infer that right amygdala activation in PTSD represents 'accentuated' responses to stimuli in this condition, and that a more subtle right hemisphere amygdala involvement might be evident in individuals without PTSD.

Thus far, it would appear that the human amygdala might play a more complex role in human emotional memory than simply forming and storing classically conditioned associations between aversive stimuli. However, it is clear that the formation of such associations on the one hand and long-term episodic memory for aversive material on the other need not be mutually exclusive functions of the amygdala. In addition, evidence indicates that the right hemisphere amygdala specifically may be involved in the processing of emotional stimuli and remembering emotional stimuli.

6.1.2. Studies of the damaged human amygdala

Further evidence for the importance of the human amygdala in long-term recall for emotional arousing material comes from studies of the memory performance of patients with damage confined to this area (Babinsky et al., 1993; Markowitsch et al., 1994; Cahill et al., 1995; Phelps et al., 1998). The patient B.P. (Cahill et al., 1995) suffers from Urbach-Wiethe disease, a rare hereditary disorder that had produced specific bi-lateral damage to the amygdala. He produced scores on attentional measures, intelligence measures and short-term memory measures in the normal range. This patient was presented with a brief narrated slide show, the Cahill stimuli [described in Chapter 3 of this thesis (also see Appendix 2 for the audio taped narrative and Appendix 3 for the recognition memory assessment for these stimuli)] depicting a story in which a mother and son leave their home to visit the boy's father. The emotional elements of this story are introduced in the second phase

of the slide presentation (e.g. an accident, and surgery). The initial first phase is relatively neutral (e.g. the mother and son leaving home, travelling to see the father etc). B.P.s self assessed emotional reaction to the story was similar to that of the controls and yet, when memory was assessed for the slide/narrative presentation in a surprise test after seven days, pronounced differences in memory were evident between the patient and the controls. The controls showed the normative enhanced memory for the second phase of the story (the emotional phase). The patient performed similarly to the controls on the first essentially neutral phase but failed to show the normative pattern of enhanced recall for the second emotive phase. This result suggested that amygdala damage was associated with memory impairment specific to emotional material.

6.1.2.1 'Conditioned fear' and/ or episodic memory?

Controversy still exists relating to whether the human amygdala underlies fear conditioning per se or long-term emotionally influenced memory. Phelps and colleagues (1998) have recently extended the single case approach to investigations of emotional memory following amygdala damage to address this question. They assessed a 54-year-old female, SP with bi-lateral AC damage on a variety of tasks. The tasks included an examination of fear conditioning, memory for differently valenced words, memory for neutral words embedded in emotional sentences, word memory changes over time, and memory performance for the same slide-story presented to the patient B.P. (Cahill et al., 1995). They found that the patient SP

failed to produce the normative pattern of enhanced memory for the middle arousing phase of the slide-story (like B.P.). They also demonstrated deficits in tests of fear conditioning with the patient (however, it should be noted that other studies of amygdala damaged patients have not shown deficits in fear conditioning – Tranel & Damasio et al., 1993). With their episodic memory tasks, Phelps et al demonstrated that whereas memory in controls would usually benefit from the effects of arousal (rather than valence), bilateral damage to the amygdala led to a deficit in arousal related memory performance. This finding indicates that a possible role for the amygdala is to modulate later memory performance by means of attending to stimuli that are arousing in nature (regardless of whether they be pleasant or unpleasant)

6.1.3. Laterality effects

The evidence briefly reviewed above indicates an important role for the human amygdala in enhanced episodic memory for material that is emotional in nature. The evidence also suggests that fear conditioning, a process disrupted after lesions of the amygdala nuclei in other animals, may also be disrupted in humans following amygdala damage (although the evidence for this in man is equivocal). The evidence accrued thus far relating to the *damaged* human amygdala indicates that bilateral damage is associated with emotional memory impairment. However, studies of metabolic activation in the healthy amygdala indicate that lateralised effects in activation of the structure are predictive of emotional memory performance. The relationship between right hemisphere amygdala activation and episodic free-recall

for emotional material suggests that the right amygdala rather than the left is more critical in terms of long-term emotional memory performance. Asymmetries in brain function have been observed in both animal and human imaging studies (Logan & Grafton, 1995; Nyberg et al., 1996; Tulving et al., 1994; Kapur et al., 1995; Squire et al., 1992). It has been suggested that encoding and retrieval may involve different hemispheres of the brain. For example, the right prefrontal cortex has been implicated in memory retrieval (Tulving et al 1994; Kapur et al., 1995) and stimulation of the left AC alone modulates memory storage in rats (Packard et al., 1994). The study reported here capitalized on a recent study indicating a clear positive relationship between right amygdala activation at encoding and subsequent recall for emotional material (Cahill et al., 1996) by assessing emotional and neutral memory performance in patients with differentially severe amygdala damage in either the left or the right hemisphere. It is possible that single case studies demonstrating emotional memory impairment after bi-lateral amygdala damage mask more subtle lateralized effects on memory. If the right amygdala is preferentially involved in memory for emotional material, then a patient with right amygdala damage should show an impairment in memory performance for the slide-story presentation similar to the performance of B.P (Cahill et al, 1995). On the other hand, a patient with amygdala damage largely confined to the left hemisphere should demonstrate memory performance on the slide materials similar to that of normal healthy adults (i.e., the patient should demonstrate an increase in memory performance for the middle 'emotive' phase of the story).

6.1.4. The current study

The current study attempted to address the possibility of such laterality of function in the human amygdala. Two patients were assessed, both patients showing evidence of bi-lateral amygdala damage. However, patient SE's amygdala damage was more severe on the right than on the left, whilst patient DR's damage was more severe on the left than on the right. Four assessments were carried out with these patients and their performance was compared with each other and to that of age, education, IQ and neutral memory matched controls. The first task involved a comparison between recall memory performance for neutral versus emotional word lists. The second task involved recall and recognition memory performance for the series of slides and accompanying narrative used in previous studies of single cases and in chapters 3 and 4 of this thesis (Cahill et al., 1995; Phelps et al., 1998). The third task sought to assess recognition memory performance and rating performance for a series of images drawn from the International Affective Picture System (Lang et al 1999) that varied in rated valence and arousal. The fourth task assessed effect on recall and recognition memory of images presented briefly to either the left hemisphere or the right hemisphere using a tachistoscopic presentation. In each task, we predicted that similar memory performance would be evident when comparing the patient with left amygdala damage ('DR') and healthy controls. However we predicted that the patient with right amygdala damage ('SE') would show a marked impairment in emotional memory relative to the healthy controls.

6.2. Method

6.2.1. Participants: (see Calder et al., 1996 for full neurological and neuropsychological profiles of SE and DR carried out in 1994)

Patient DR, a right- handed female (58 at start of testing in 1997) underwent a series of operations between 1978 and 1981 in an attempt to control epilepsy from which she has suffered since the age of 28. These surgical interventions targeted the amygdala. MRI indicates an extensive lesion to the left medial amygdala affecting the basal nuclei and sparing the lateral nucleus. The damage extended throughout the rostro-caudal limits of the left amygdala reaching the anterior horn of the left hippocampus. Associated damage extends dorsally beyond the amygdala involving part of the anterior commisure, lateral putamen and external capsule. In the right hemisphere, there was a small posteriorly placed lesion in the right anterior amygdaloid area (see Young et al., 1995 for tracings of these lesions). DR has longstanding damage to the amygdala in both hemispheres therefore; however, her damage is more severe in the left amygdala than in the right amygdala.

SE, a right- handed male (65 years old at start of testing in 1996) suffered from presumed herpes simplex virus encephalitis at 55 years of age. MRI indicates extensive destruction of the right temporal pole, uncus, amygdala (all nuclei), hippocampus, hippocampal gyrus, and inferior and middle temporal gyri to the level

of the insula. The left cerebral hemisphere was normal apart from a small region of high signal in the T2 weighted sequence in the region of the uncus and antro-medial amygdaloid area (for MRI scans see McCarthy et al., 1996). SE showed evidence of long-standing bi-lateral damage to the amygdala; this damage was however, more severe in the right hemisphere amygdala than the left.

Neuropsychological test results on these two patients are presented in Calder et al., (1996). Both patients demonstrated an estimated pre-morbid IQ (as assessed by the National Adult Reading Test – NART – Nelson, 1981) in the average range. However, assessments of DR with another measure of current intelligence, the WAIS-R (Wechsler, 1981), indicated that predicted pre morbid IQ was above both pre and post operative results with the WAIS and WAIS-R (Young et al., 1995). SE's WAIS-R and NART both indicated average intelligence. In addition Calder et al., (1996) found no evidence of impairment of basic visual functions with full visual fields to confrontation and normal spatial contrast sensitivity function (Vistech VCTS 6000) in both SE and DR. This finding supports the assertion that any detriment in performance associated with the experimental stimuli in the Calder et al study (1996) could not be associated with poor vision per se.

In the study reported here, DR and SE's performance on a different set of tasks was again compared to that of 10 healthy control participants matched for current and school leaving age (as was done in the Calder et al., 1996 study). The participants in the current study were chosen to match both SE and DR on a number

of variables (see Table 6.2). The controls were drawn from the local community in St Andrews, in Fife. Three were Janitorial staff at the University of St Andrews, three were cleaning staff at the University of St Andrews, a further 2 participants worked as laboratory technicians in the medical faculty of the University. A further two were the spouses of university employees. In addition to matching controls and patients in terms of current and school leaving age, the present study attempted to match controls and patients in terms of both predicted pre-morbid IQ (NART) and neutral word memory performance (California Verbal Learning Test – Delis, 1987).

6.2.2. Study part 1. Emotional stimuli: Slide/story presentation.

On arrival, participants had their general (non-emotional) memory assessed using the California Verbal Learning Test (Delis, 1987). This assessment has both short delay and long delay recall and recognition items. The long delay tests are administered with 20 minutes between presentation and test. The NART assessment of predicted pre morbid IQ was administered during the interval. Participants were then shown a series of slides accompanied by a narrative. The slide stimuli employed in this study were similar to the material employed by Cahill and colleagues (Cahill, 1994) but differed in that only the 'emotional' slide narrative presentation was used. This protocol was identical to that employed by O'Carroll et al 1999(a), 1999(b) and in Chapters 4 and 5 in this thesis. Participants were seated in a comfortable chair in a darkened, sound proofed room while a series of 11 slides were projected for 20 seconds per slide, onto a white screen (6ft by 4ft) eight feet

from them. A short audio taped narration accompanied each slide (see Appendix 2. for this narrative).

For the purposes of analysis, the slide narrative presentation can be divided into the three phases. The first phase contains essentially emotionally neutral information relating to the protagonists, to the mother and son leaving home to visit the father and their journey. Emotionally arousing information is introduced in the second phase concerning the car accident, the hospital and the subsequent surgery and the final phase deals with the aftermath of these events (the alternative arrangements that have to be made by the mother to collect her other child). Immediately following the completion of the slide/narrative presentation, participants were required to indicate how emotionally arousing they found the presentation by placing a mark on a visual analogue scale ranging from 1 (not at all emotional) to 10 (very emotional).

6.2.2.1. Second session - 7-day interval:

One-week following the initial session participants returned for a final session. Participants were told that this final session would involve administration of a further series of 'pencil and paper' type assessments similar to those carried out in the first session and that the session was required to reduce the 'workload' in the first session. The test of recall for the slide narrative series involved participants being asked to freely recall as many of the slides as possible from the presentation a week earlier. They were asked to describe them in as much detail as possible and were prompted to recall both the story line as well as particular details, ('colour of

clothing' and the 'direction that people were walking' were given as examples of the kinds of details to try and recall). Participants were told to take as long as they needed and following a response of 'that is all I can remember' were reminded that they had seen a total of 11 slides. The participants were then asked to repeat the free-recall exercise so that the experimenter could "assess which of those 11 slides you have any memory of seeing". Participants were asked to move through as many of the eleven as they could remember, describing each in detail.

Following the free-recall memory assessment, the participants were required to verbally respond to a series of multiple choice memory questions designed to assess recognition memory (these are described in O'Carroll et al., 1999b – see Appendix 9 for the recognition memory questions). In addition to the multiple choice recognition memory questions, participants were required to perform an emotional word memory task similar to the California Verbal Learning Test but which employed Affective words, known as the Affective Auditory Verbal Learning Test - AAVLT (Snyder & Harrison, 1997). This assessment was carried out in order to compare memory for neutral words (CVLT) and emotional words (AAVLT) in the participants with amygdala damage and the controls.

At the end of the second session, participants were debriefed and asked if they had guessed that their memory for the slide/narrative series would be assessed. None indicated that they had.

6.2.2.1.1 Hypothesis relating to the slide stimuli and words

It was predicted that the patient with damage to the amygdala more severe in the left hemisphere than the right (DR) would demonstrate the normative pattern of

enhanced recognition memory performance for the second, middle emotive phase of the slide-story. The performance of this patient would be similar to that of controls in this respect. However, the patient SE with damage to the amygdala more severe in the right hemisphere than the left hemisphere would fail to show the normative pattern of enhanced recognition memory performance for the middle emotive phase of the story presentation.

In terms of verbal memory performance it was predicted that the patient DR would perform similarly on assessments of both neutral (CVLT –Delis 1987) word memory *and* emotional word memory (AAVLT – Snyder & Harrison 1997). However, by comparison, it was predicted that SE would produce similar neutral word memory scores to controls and DR but show a marked impairment in memory for emotional words.

6.2.3. Study part 2a. Central exposure. (Subjective ratings and memory performance)

6.2.3.1. Materials and procedure

Following the recognition memory assessment for the 11 slides accompanied by a story administered during the second session, participants were presented with 20 images at 10- second exposure in the centre of a Macintosh PowerBook 3400C 'laptop' style computer. Images depicted scenes that differ on dimensions of arousal and valence (drawn from the International Affective Picture System. IAPS - Lang et

al. 1999. Technical reports A-4, The Center for Research in Psychophysiology, University of Florida). N.B. for ethical reasons only mildly arousing stimuli were employed (e.g. a staged abduction/snarling dog etc.). These stimuli were identical to the stimuli displayed to the 'image alone' group in Chapter 3 of this thesis, and details concerning the valence/arousal ratings assigned to the stimuli by the normative sample are available in Chapter 3 section 3.2). In addition, see Appendix 7 for a detailed summary of the images employed.

Control participants were presented with the identical series of 20 images depicting various scenes in the same order as the patients SE and DR. The order of presentation for SE, DR and controls was random. Any given image chosen for the present study had received a high, low or neutral valence and arousal rating in the normative procedure. Ratings for arousal and valence ranged from low to high (1 – 9). The distribution of IAPS images in the 'affective space' defined by valence and arousal ratings assigned to them meant that images could not be drawn from equivalent valence and arousal vectors (see methods section – Chapter 3). During presentation, in response to visual stimuli, all participants completed an affective rating system for valence (degree of 'pleasantness/unpleasantness') and an affective rating system for arousal called the Self Assessment Manikin (Lang et al., 1999). The self assessment manikin (SAM) used in this study consisted of a graphic figure depicting values along each of the two dimensions of valence and arousal on a continuously varying scale (for examples of the manikin used in this study see Appendix 6.) The SAM rating system has been extensively used in conjunction with

the International Affective Picture System – IAPS that is described below (also see Lang et al., 1999 for published studies using the IAPS system).

Following the rating exercise (described in Chapter 3 and 4), a brief test of emotional word memory was administered (Snyder & Harrison, 1997). This word memory assessment is similar to the CVLT described above. Participants are read a series of five 15-word trials. Each of these five trials contains the same 15-word list. After each trial participants are required to repeat back as many of the words as they can remember. Following the fifth trial, participants are read a list of 15 neutral words and are required to recall as many of these as they can remember. The short-term recall assessment involves participants attempting to recall as many words from the original five trial lists as possible. This recall test occurs immediately following the recall of the neutral (distracter) word list. After a period of 20 minutes, participants are again required to recall as many of the original affective words as possible.

After this half- hour filled interval, participants were presented with 40 images, 20 of which had been presented and rated before. Response latencies to the question 'have you seen this picture before' were recorded. Participants were required to respond to the presentation by pressing a marked key ('y' for 'yes') if they thought they had seen an image before and a key marked 'n' for 'no' if they thought they had not seen a presented image before.

6.2.3.2. Main hypothesis for study part 2a:

Participants with right amygdala damage will show impaired memory for emotional material (words and images) at the recognition memory test compared to a normal response in patients with left amygdala damage.

6.2.4. Study part 2b. Brief lateral exposure (hemispheric differences).

The procedure for this study was identical to that in study part 2a. However, a further set of 20 IAPS images were presented to either the right or the left of a central fixation point for a period of 80 milliseconds each. These briefly presented images were drawn from the same source as the images employed in part 2a but differed from the images used in that part of the study. These images were presented to either the left or the right of a central fixation point to assess possible effects on memory of initial representation of images varying in dimensions of valence and arousal when presented to the left or right hemisphere. Visual pathways are crossed in the human brain and thus visual fields are represented in each hemisphere. All the field left of the fixation point is represented in the right visual cortex, and the entire field right of the fixation point is represented in the left visual cortex (See Kolb & Whishaw, 1990). Complex visual stimuli depicting human faces have been tachistochopically presented to left and right visual cortices in commissurotomy

patients in previous studies of facial recognition (Levy et al., 1972). Reliable differences in recognition memory have been demonstrated employing 8 stimuli presented to such patients. The use of 80 millisecond tachistoscopic presentations was based on Sergent's (1982) study of the consequences of variations in exposure duration in visual laterality studies. She highlights two conditions that must be met in such studies to ensure that information from one visual field is initially projected to the contra lateral hemisphere: (1) the stimulus must be presented to the left or right of fixation and (2) the duration of exposure must be 150 msec or less – to prevent eye movements that could expose the stimulus to both hemispheres.

Ratings for arousal and valence for the new set of 20 stimuli employed in the current study ranged from low to high (1 – 9). The distribution of IAPS images in terms of valence and arousal ratings assigned to them meant that images could not be drawn from equivalent quartiles of valence and arousal... see table 6.1. [for example, few low valence, low arousal images exist because a low valence image (i.e. an image that is very unpleasant) is seldom rated as not being highly arousing]

Table 6. 1. The valence and arousal ratings assigned to images in the normative study (Lang et al., 1999) that were averaged over 5 categories employed in the present study.

Emotion category	Valence (SD)	Arousal (SD)
Low valence high arousal	2.33 (.20)	6.65 (.47)
Low valence low arousal	3.37 (.34)	5.95 (.96)
Neutral	5.01 (.21)	3.32 (.49)
High valence low arousal	8.04 (.30)	4.85 (.42)
High valence high arousal	7.46 (.24)	6.92 (.33)

Four of the 20 images selected for the present study had received low valence (pleasantness) ratings and high arousal ratings (see Table 6.1, Low valence,

high arousal category). These images were selected for the present study from IAPS images that had received a valence rating of between 1 and 4 and an arousal rating between 5 and 7 in the normative study. Seven was set as the upper limit for these images and not nine because of the potentially distressing nature of the images rated between 1 and 4 on the valence scale and between 5 and 9 on the arousal scale. These four images constituted the 'low valence high arousal category' (LVHA). Four of the 20 images constituted the 'Low Valence Low Arousal' category (LVLA) and had received valence ratings between 1 and 4 and arousal ratings of between 4 and 6 in the normative study. Four and six were chosen to represent low arousal in this category instead of 1 and 4 because few items had been collected by the authors of the normative study that had received arousal ratings between 1 and 4 alongside low (1 – 4) ratings of valence by the raters. Indeed, by definition, it is unlikely that many images exist that receive extremely low ratings of valence (denoting extreme unpleasantness) while receiving low ratings for arousal. The four neutral images used in this study received valence ratings between 4 and 6 and arousal ratings of between 3 and 5. High valence low arousal images (HVLA) were drawn from images that had received valence ratings between 6 and 8, arousal ratings between 3 and 5. Finally high valence, high arousal images (HVLA) received valence ratings between 6 and 8 and arousal ratings between 6 and 7. For ethical purposes, selection of images from the valence and arousal ranges in the corpus was not random. Two major themes were excluded. One theme related to sex, the other related to images of the victims of real life homicide/murder, again for ethical

reasons only. Only moderately arousing stimuli were used in this study, sufficient to produce a mild emotional response.

Therefore there were 20 images in total, 4 in each of five emotion (valence/arousal) categories. Within each category 2 images would be presented on the left hand side of a 14" screen and 2 images would be presented on the right hand side. The images were approximately 7" by 4" each.

An initial test of the participants' explicit memory for the content of each image was made ten minutes after the presentation (during which, participants completed a simple filler task involving the naming of colours in order to avoid effects of rehearsal). Participants were required to freely recall information about any of the images that they remembered seeing. Thirty minutes later, a recognition test was administered consisting of 40 items presented centrally (20 of, which had been presented previously). Further filler tasks were completed during this 30-minute interval (copying a complex Rey/Ostereith type image in its original orientation while imagining it rotated through 90 degrees and completing the Block Design task of the WAIS-R – data on these tests will not be presented).

6.2.4.1. Main hypothesis for study part 2a:

Participants with right amygdala damage will show impaired memory for emotional material (words and images) at the recognition memory test compared to a normal response in patients with left amygdala damage.

6.2.4.2. Main hypothesis for study 2b:

There will be no difference between the recognition memory and reaction time of patients with damage sparing the right amygdala and age matched controls. Patients with right amygdala damage are expected to show impaired memory and an increase in reaction time to specifically emotional images presented to the right hemisphere as compared to controls and patients with damage sparing the right amygdala.

6.2.5. Analysis

The performance of healthy age and education-matched controls were compared to the patient SE and the patient DR using a modified version of a paired sample t-test (Crawford and Howell, 1999). The usual method for comparing an individual's score with that of a sample of normal individuals in human neuropsychological research is to convert the score to a z-score. The z-score is a standard score and represents in terms of standard deviations, the amount a score

deviates from the mean of the population from which it is drawn. A z-score falling above +1.64 would represent a score that fell above the 95th percentile and would therefore be considered significant at the conventional .05 level. However, as Crawford and Howell (1998) have pointed out, the z-score analysis treats the normative sample to which a score is compared as if it were a population, and often, the normative sample is not sufficiently large enough to be treated as such. When the sample is small it is arguably more appropriate to treat the individual as a sample of n=1 and use a modified t-test first described by Sokal & Rohlf, (1995) to compare effectively the mean of the group of n=1 with the mean of the normative sample. This approach has been adopted here. Probability is expressed as a two-tailed value unless otherwise stated because specific predictions were made concerning the 'direction' of differences between patients and controls.

6.3. Results

6.3.1. Matching the healthy controls with SE and DR.

Attempts were made to match the control participants with SE and DR in terms of age at the start of the present study, school leaving age, predicted pre-morbid IQ as expressed by the NART error score and general memory functioning as expressed by the number of neutral words recalled over the first 5 trials of the California Verbal Learning test. These results are displayed in Table 6.2. Control means for the different variables were compared to the scores of SE then DR using a

modified paired sample t-test (df = 9). No significant differences were observed between patients and controls on potentially confounding variables.

Table 6.2. Controls and patients are matched on potentially confounding variables.

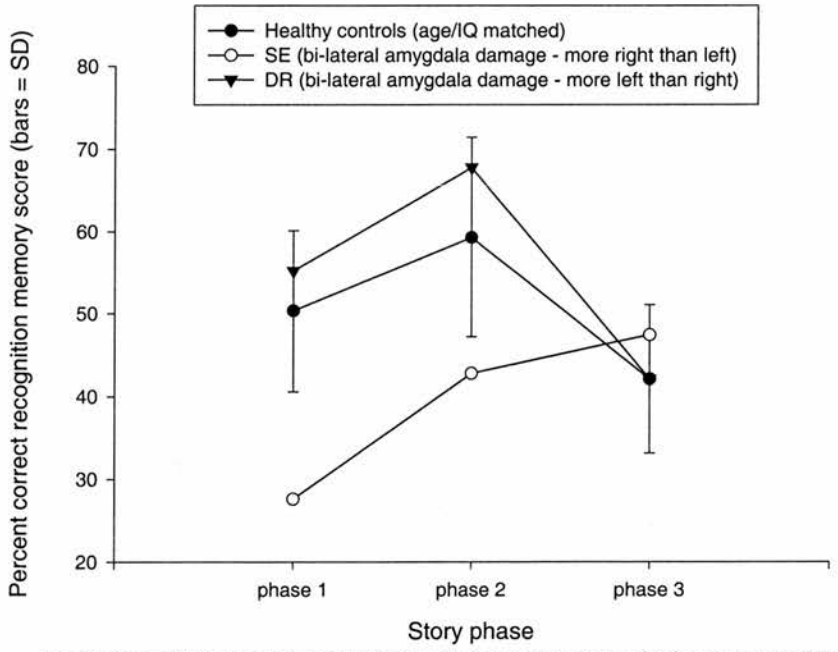
Subject Matching variable	Controls (SD)	SE	DR	SE vs Cont.	DR vs Cont.
Sex	6 males, 4 females.	M	F		
Age	58.5 (6.34)	65	58	T = .98, **p = .35**	T = .94, **p = .94**
School leaving age	15.1 (.88)	15	15	T = -.11, **p = .92**	T = -.11, **p = .92**
IQ – (NART)	105.7 (8.06)	100	111	T = -.67, **p = .52**	T = .63, **p = .55**
Neutral memory (CVLT trials 1-5)	61 (14.11)	40	45	T = -1.42, **p = .19**	T = -1.08, **p = .31**

6.3.2. Memory performance for the Cahill 11 slide story (see Figure 6.1.)

All participants were presented with the Cahill 11 slide-story at an initial session and immediately following the presentation were required to complete a self assessed emotional reaction scale. (0 = not at all emotional – 10 = highly emotional), Controls participants' mean rating was 6.0 (SD = 2.16). SE's rating was 4. There was no significant difference between SE's rating of 4 and the control sample's rating of 6.0 (SD = 2.16) [t (9) = -0.88, p = .4]. DR produced a rating of 9, however, her rating was also not significantly different from the ratings of the control sample [t (9) = 1.32, p = .22]. One-week following the Cahill 11 slide-stimulus presentation all participants received a 'surprise' memory test consisting of a multiple choice recognition memory test for the stimuli presented one-week previously.

Figure 6.1 displays the recognition memory performance means for the control participants, SE and DR respectively. Analysis of recognition memory performance by phase of story presentation indicated the normative pattern of increased recognition memory performance for the middle emotive phase of the story for the control participants in this study. Repeated measures ANOVA on recognition scores for the control sample revealed a significant effect of phase of story on percent recognition memory score [F (2,18) = 19.73, p = .01]. The patient DR showed the normative pattern of enhanced recognition for the second emotional phase of the story presentation compared to the first and third phases. However, the patient SE failed to show the normative pattern of enhanced recognition for the second phase of the presentation compared to the third phase. Essentially, there was no evidence of a normative 'peak' in memory performance for the emotional second

Figure 6.1. Recognition memory performance for the 11 slide series



[SE (right amygdala damage) does not show the normative pattern of enhanced recognition for the second emotional phase of the story. DR (left amygdala damage) shows the normal pattern]

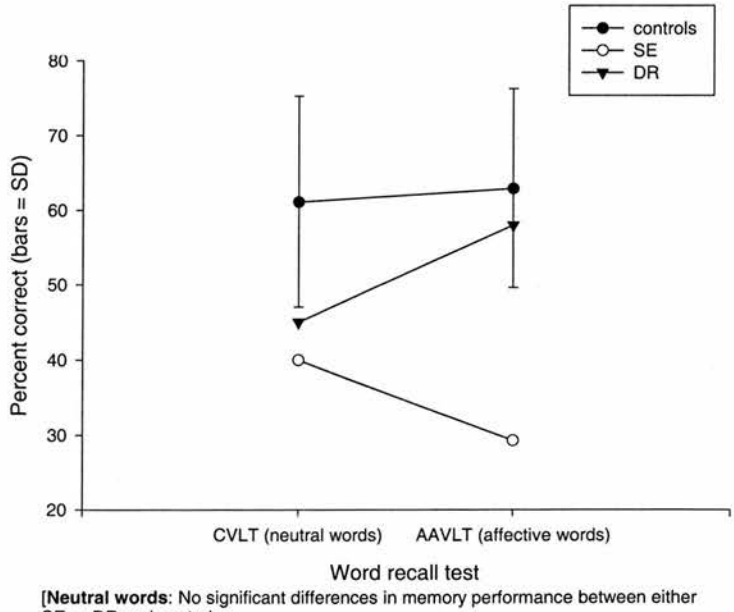
phase for SE (see Figure 6.1.)

To summarize the recognition memory scores, only patient SE, with extensive right amygdala damage, failed to show the enhanced pattern of recognition memory scores for the middle emotional phase of the story presentation. Both DR and controls showed an increase in memory scores for this phase.

6.3.3. Memory for neutral and affective word lists (see Figure 6.2.)

In addition to the 11- slide presentation and subsequent memory assessment for the slides, two brief tests of verbal memory were carried out with both patients and controls. One assessment comprised neutral words (CVLT), the other emotional words (AAVLT). A comparison of the performance of the control group with patient DR revealed no significant differences between performance on either the neutral

Figure 6.2. Performance over the first 5 recall trials of the California Verbal Learning Test (CVLT) and the Affective Auditory Verbal Learning Test (AAVLT)



[**Neutral words**: No significant differences in memory performance between either SE or DR and controls
emotional words: No significant difference between DR and controls but significantly lower memory score for SE versus controls]

word memory task [t (9) = -1.09, p = .30] or the affective word memory task [t (9) = -0.31, p = .77] – (see Figure 6.2.) However, while the patient SE and controls did not differ in performance on the neutral word memory task [t (9) = -1.43, p = .19), SE scored significantly lower than controls on the emotional word memory task [t (9) = -2.41, p = .04] – see Figure 6.2.

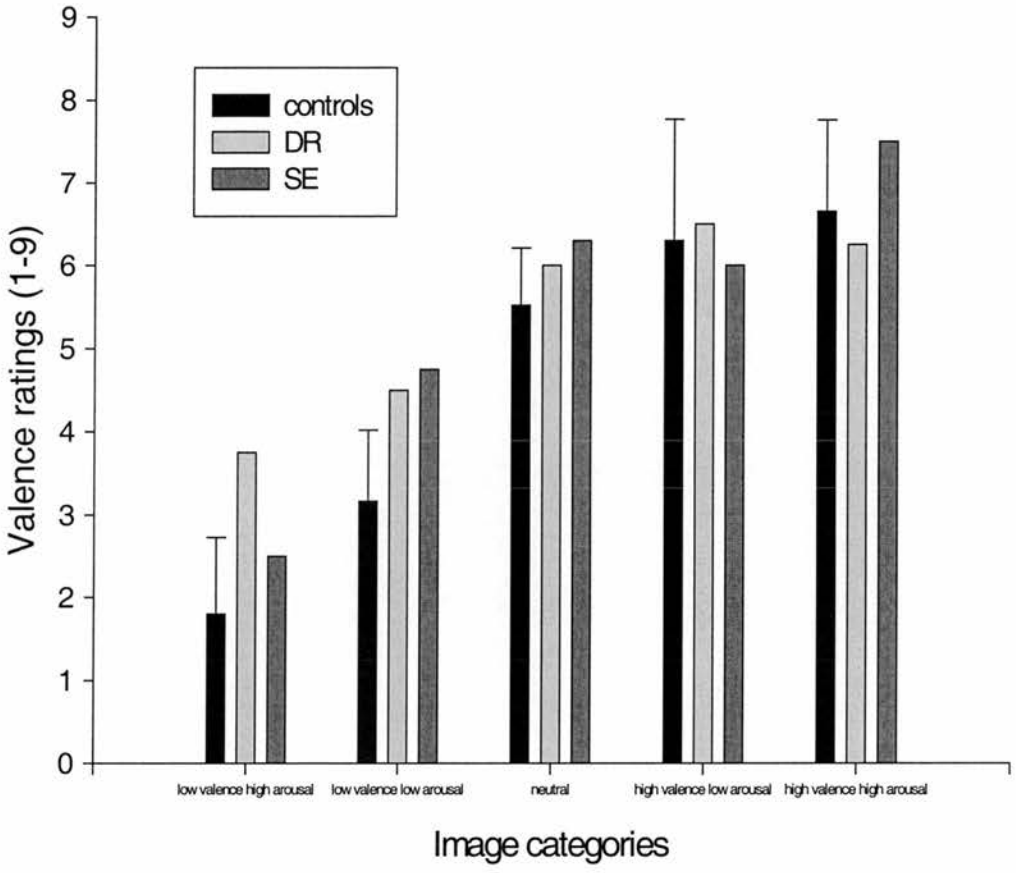
In summary, there was no significant difference between the performance of DR and the performance of controls on both the neutral and emotional word memory tasks. However, SE produced significantly lower scores than controls on the emotional word memory task and not the neutral word memory task.

6.3.4. Self-ratings of images presented centrally (see figure 6.3 for valence ratings and Figure 6.4 for arousal ratings).

Figures 6.3 and 6.4 present the self-ratings of valence and arousal respectively assigned to the categories of images presented to controls and patients in a central position on the screen. Figure 6.3 represents valence self-ratings. Modified paired sample t-tests revealed no significant differences between ratings assigned to categories by SE, DR and controls. Valence ratings for all participants increase in line with categories such that least pleasant categories (Low valence high arousal; low valence low arousal) received the lowest valence ratings and most pleasant categories (high valence low arousal; high valence high arousal) received the highest ratings of valence. Figure 6.4 represents self- ratings of how aroused a subject felt when viewing images from each category. Again, modified paired

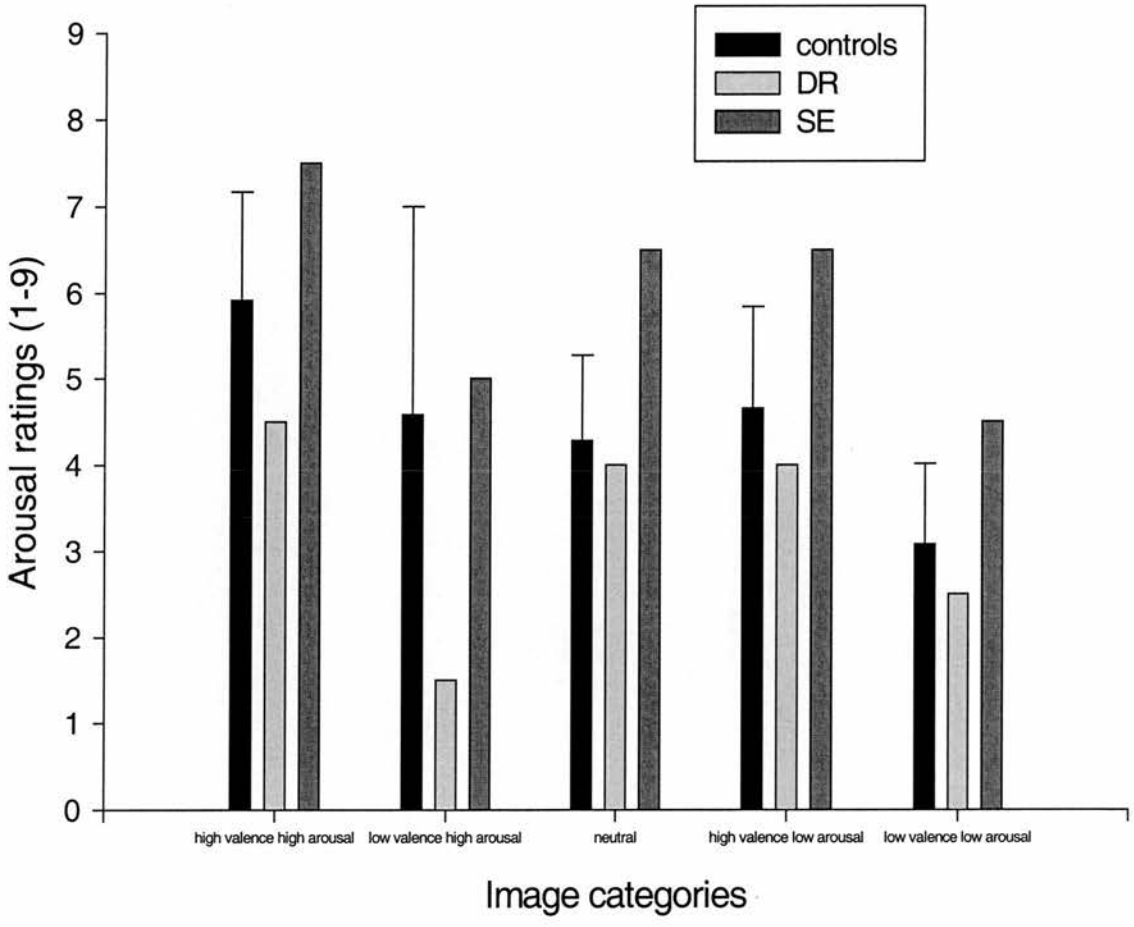
sample t-tests revealed no significant differences between the ratings assigned to images by controls and the ratings assigned to images by patients. A comparison of figures 6.3 and 6.4 indicate that no significant differences exist between the control group and the patients on valence or arousal ratings, valence ratings closely follow category valence levels (as defined by the original normative study) for both patients and controls. In Figure 6.4 however, while the pattern of arousal ratings follows the levels expressed in each category in the control group this is not the case for the two patients' arousal ratings, e.g. for DR, the LVLA arousal rating is higher than LVHA.

Figure 6.3. Valence ('pleasantness') ratings assigned to image categories by SE, DR and matched healthy controls.



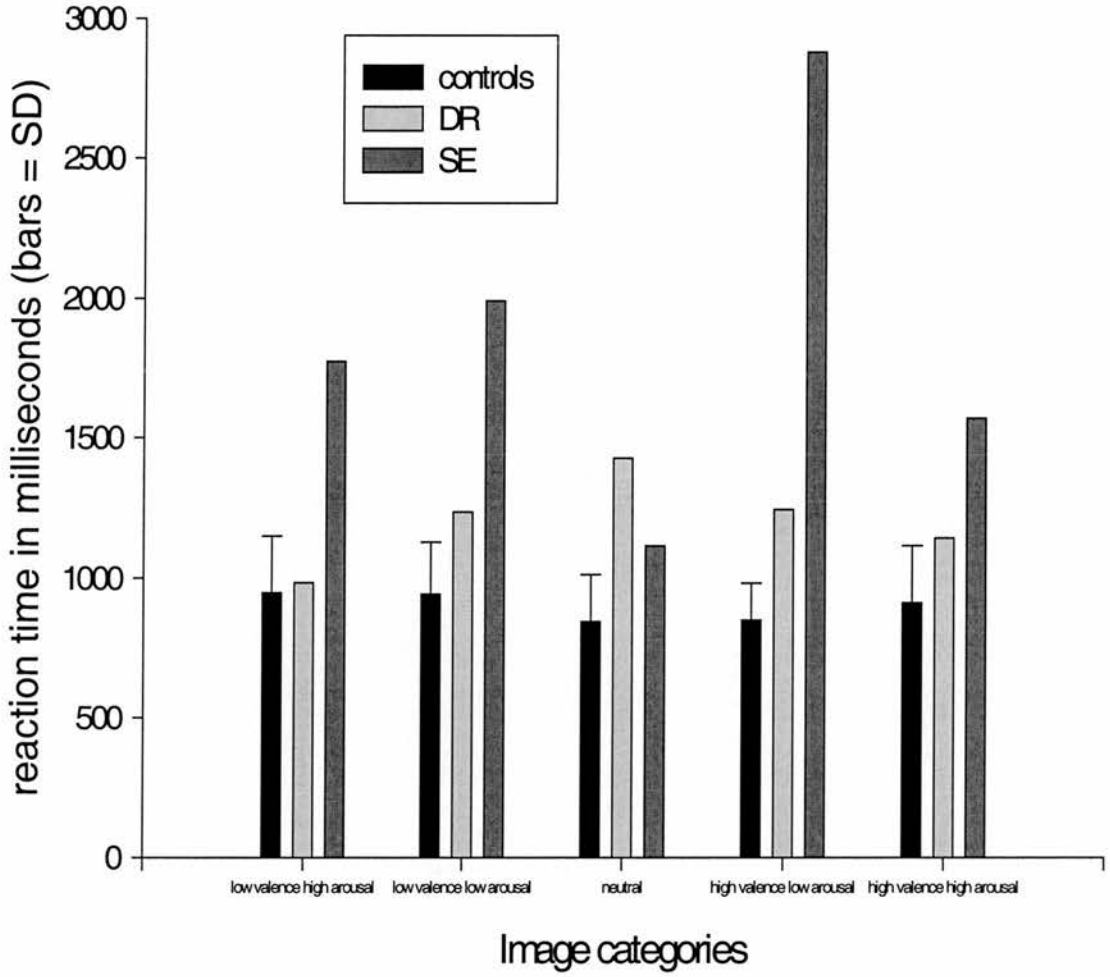
[No significant differences between SE, DR and controls]

Figure 6.4. Arousal ratings assigned to image categories by SE, DR and matched healthy controls.



[No significant differences between SE, DR and controls]

Figure 6.5. Time to respond correctly in the central recognition memory task



[For low valence low arousal category, the low valence high arousal category, and the high valence high arousal category, SE produced significantly greater reaction times than controls and DR's reaction times were not significantly different from controls.
For the neutral category and the high valence low arousal category, both SE and DR's reaction times were significantly greater than controls.]

6.3.5. Recognition memory performance for centrally presented pictures (see Figure 6.5.)

All participants operated at ceiling in the recognition task by correctly identifying images as either presented previously or not presented previously. Figure 6.5 represents the time taken to respond correctly to images presented at a recognition test, half of which had been presented previously and had been rated by all participants. Participants responded to the question 'have you seen this image before and were required to press 'Y' for yes as quickly as possible if they thought they had seen it before (when rating images) and 'N' for no, if they thought they had not seen the image before.

The time taken to correctly recognize images presented that made up the neutral category indicated that both SE and DR took longer to respond correctly than age matched controls [Neutral images: DR vs controls: $t(9) = 3.30$, $p = .01$. SE vs controls: $t(9) = 2.48$, $p = .03$] – see Figure. 6.5. SE's reaction times were closer to controls than DR's reaction times in the neutral category. This same pattern of reaction times was evident in the high valence, low arousal category in that both SE and DR produced significantly greater reaction times in the recognition test than controls [HVLA: SE vs controls: $t(9) = 14.7$, $p = .01$. DR vs controls: $t(9) = 2.84$, $p = .02$].

However, reaction time for all low valence categories (low valence high arousal; low valence low arousal) and the high valence, high arousal category

indicated that SE produced significantly greater reaction times than controls while DR's reaction times did not differ significantly from controls. In the low valence, high arousal category SE produced significantly greater reaction times than controls [t (9) = 3.91, p = .01] while the performance of DR was not significantly different from the performance of controls [t (9) = .17, p = .87]. For the low valence low arousal category, SE's performance was significantly greater than controls [t (9) = 5.39, p = .01] while the performance of DR was not significantly different from controls [t (9) = 1.50, p = .17]. Finally for the high valence high arousal category, SE's performance was significantly greater than controls [t (9) = 3.08, p = .01] while DR's performance was not significantly different from controls [t (9) = 1.08, p = .31]. For analysis of error rates in the recognition memory assessment, see Appendix 10).

To summarize the results of the reaction times in the recognition test for images presented in a central position on the screen and rated earlier, for low valence categories of images (ie least pleasant), DR took the same amount of time to react to images as being familiar as did controls. However, SE took significantly longer than controls to react to images as familiar for these categories. However, with neutral images, the reaction time of SE was closer to that of controls than the reaction time of DR. With the high valence categories of images (most pleasant) SE consistently reacted significantly more slowly to images than did controls while DR only reacted more slowly than controls when high valence images were also rated as being 'low' arousal. Thus, SE, with largely right-sided amygdala damage,

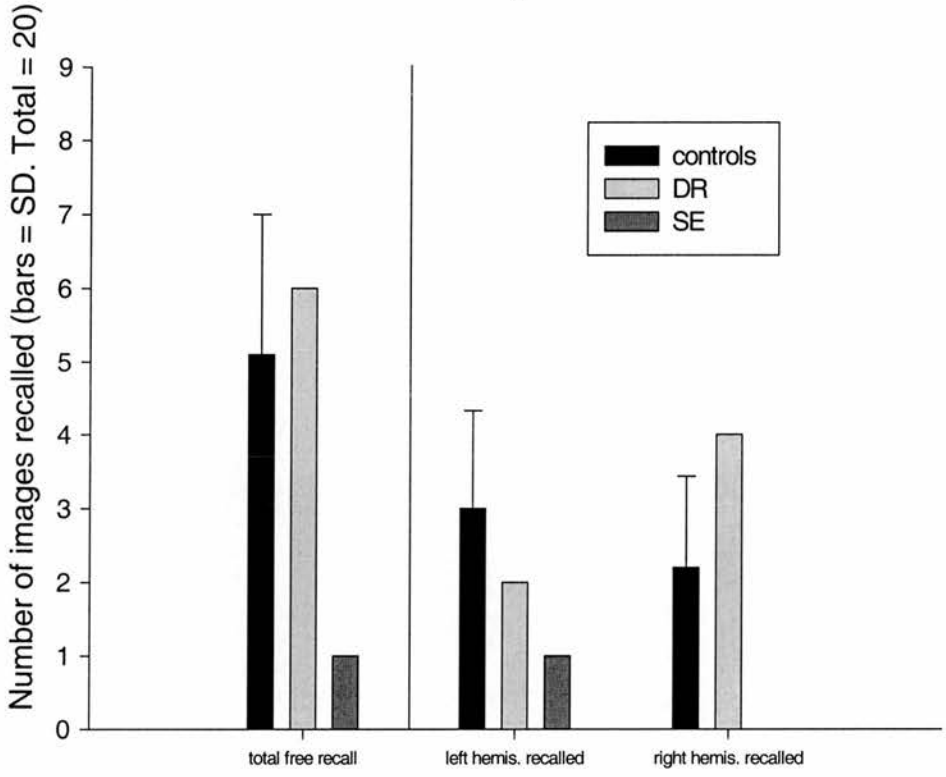
demonstrated an abnormally slow reaction time for emotional but not neutral images presented to him.

6.3.6 Brief Lateral presentations: Free-recall of images presented to the right hemisphere compared to free-recall of images presented to the left hemisphere (see Figure 6.6.).

Employing the modified paired samples t-test, an analysis of free-recall memory revealed no significant differences between controls and DR in total free-recall memory performance for the lateralised slide presentations [DR: t (9) = .44, p = .67.]. However, SE demonstrated a significantly lower free-recall score than controls [SE: t (9) = -2.06, p = .03 (one tailed), p = .07 (two tailed)]. DR's score was above that of the controls, while SE's score was well below that of controls (approximately 2 standard deviations below the mean of controls). When free-recall scores were broken down into the number of images freely recalled that had been presented to the left hemisphere, DR again performed within one standard deviation of the mean free-recall score of healthy controls [t (9) = -.72, p = .49] while SE's performance was at floor. He performed out-with the normal range, but not significantly so. [t (9) = -1.43, p = .19]. Therefore, both SE and DR did not perform significantly differently from controls when recalling images that had been presented to the left hemisphere. When free-recall scores were analyzed in terms of the number of images freely recalled that had been presented to the right hemisphere, DR's score

was not significantly different from controls [t (9) = 1.39, p = .19] while SE failed to recall any images that had been presented to the right hemisphere [SE versus controls: t (9) = -1.75, p = .11 (two tailed). t (9) = -1.75, p = .05 (one tailed)].

Figure 6.6. Lateralized presentation: Free recall total, and as a function of side of presentation.



[**Total free recall:** SE's total free recall score was significantly lower than controls. DR's total free recall score was not significantly different from controls.]

[**Left hemisphere recall:** No significant differences between controls and either SE or DR. **Right hemisphere recall:** SE's recall of images presented to the right hemisphere was significantly lower than controls, while SE's recall of right hemisphere images was not significantly different from controls.]

6.4. Discussion

6.4.1. Amygdala damage and memory for the slide-story materials (Figure 6.1)

The control participants in the present study were well matched, with both SE and DR on potentially confounding variables such as age, pre-morbid IQ, school leaving age and neutral word memory scores. Results indicate that SE, whose amygdala damage is more severe in the right hemisphere than the left, failed to show the normative pattern of heightened recognition memory performance for the second emotional phase of the Cahill slide/story presentation. His emotional reactions to the stimuli were normal, but he showed evidence of abnormal emotional memory functioning. DR's emotional reactions to the stimuli were also normal, however, both controls and the patient DR showed the expected increase in recognition memory performance for the second, emotional phase. This finding suggests that amygdala damage that is more severe in the right hemisphere than the left corresponds with a failure to show a normative peak in memory performance for the emotional elements compared to the neutral elements of the slide-story presentation in the face of normal subjective emotional responses to stimuli at encoding.

6.4.2. Amygdala damage and memory for emotional and neutral words (Figure 6.2)

The healthy control participants in this study, along with both SE and DR completed two widely used neuropsychological assessments of verbal memory. One of these tests contained relatively neutral words (spices, herbs, tools, clothing etc) the other test contained negatively valenced emotional words (infections, negative emotions, dangerous weapons etc). Scores on the measure of neutral word memory were not significantly different when the controls were compared with either SE or DR. All participants produced a similar number of neutral words in the free-recall assessment. Critically, when the patients and the controls were assessed on their memory performance for the emotional words, only SE showed a significant deficit in memory relative to controls. DR performed at the same level as controls in her memory for the emotional words. This finding indicates that when memory is assessed for both neutral and negatively valenced emotional words, right hemisphere amygdala damage corresponds with memory impairment relative to healthy people for emotional words but not neutral words. This pattern is not seen in the patient reported here whose damage largely affected the amygdala in the left hemisphere (DR). This finding provides further evidence that right hemisphere amygdala damage (and not necessarily left hemisphere amygdala damage) may result in a selective memory impairment for emotional but not neutral material.

6.4.3. Amygdala damage and memory for a *range* of emotional material represented by different categories (pleasant – unpleasant (valence), high arousal – low arousal).

In addition to the assessments of memory for the emotional slide-story and memory for words, the effects of lateralised amygdala damage were assessed for images that varied in rated levels of valence and arousal. Essentially, the slide-story, discussed above, compares memory for relatively neutral material with negatively valenced emotional material. The tests of word memory employed in this study, in addition to the assessment of memory for the slides, used neutral words and negatively valenced emotional words. It appears therefore that amygdala damage that is more severe in the right hemisphere than the left, affects memory for negatively valenced emotional material. However, it is difficult to draw this conclusion with confidence without comparing memory performance for negatively valenced material with both neutral and positively valenced (ie pleasant) material. For example, some authors (Phelps et al 1998) have found that the amygdala is associated with arousal mediated memory more so than valence mediated memory (see introduction of this chapter). This would suggest that memory for highly arousing images, be they pleasant or unpleasant should depend on the amygdala and that damage to the amygdala should affect memory for the highly arousing images, be they pleasant or unpleasant (high or low valence).

Images for the second phase of the study were chosen to vary in terms of the emotional valence and arousal ratings assigned to them in normative studies. Using

these 'IAPS' images (International Affective Picture System') described in previous chapters of this thesis (see Chapter 5.), allowed for a more detailed investigation of the nature of the emotional memory impairment following amygdala damage. Memory performance could be assessed for the range of emotions represented by levels of valence [pleasantness (Figure. 6.3)] and levels of arousal (Figure. 6.4). Figures 6.3. indicates that when patients rated the different categories of images that were presented on the computer screen, amygdala damage was associated with valence and arousal ratings that were not significantly different from controls. With respect to valence ratings specifically, both the patients' ratings were similar to those of the healthy controls in as far as low valence ratings were assigned to low valence categories and high valence ratings were assigned to high valence categories for all participants.

However, while the subjective ratings made by SE and DR did not differ significantly from the subjective ratings of age and education matched healthy controls, recognition memory performance (reaction times) did differ significantly between the patient SE and controls. DR took the same amount of time to react to images as being familiar as did controls, however, SE took significantly longer than controls to react to images as familiar in these categories. One explanation for this slowed responding in SE may have been an idiosyncratic slowed responding across all tasks. However, with neutral images, the reaction time of SE was closer to those of controls than the reaction time of DR. This indicates that SE demonstrated slowed responding to emotional images that was more pronounced than the slowed responding to neutral images. It also indicates that right amygdala damage

contributes to an emotion specific reduction in reaction times relative to left amygdala damage (i.e. only right amygdala damage, not left, was associated with slowed responding to emotional images).

6.4.4. Memory for images presented briefly on the left and the right of a central fixation point. (Figure 6.6).

To summarize the results of the brief lateralized presentation, DR's performance was not significantly different from controls in terms of the total number of images recalled that had been briefly presented to either the left or right hemisphere earlier. SE was only significantly impaired when stimuli were presented to his right hemisphere. Error rates were most pronounced (i.e. either at 100% or at or below chance – see Appendix 10) for the two high arousal categories (both high valence high arousal and low valence high arousal). In addition SE but not DR produced a significantly higher percentage of responses that were errors to the neutral category of images in the recognition test. When recalling images that had been presented to the left hemisphere during the presentation phase, DR performed within the normal range but SE did not. When recalling images that had been presented to the right hemisphere, SE failed to remember any, but DR remembered more than any of the individual controls. However, the difference between DR's performance and that of controls was not significant. To summarise, the patient SE was only significantly impaired in his recall of slides presented to his damaged right hemisphere.

6.4.5. Cautionary notes

The results of the brief lateralised presentation and the central presentation should be treated with caution. Due to the nature of this study and the patients being tested, the images selected for the study had to be restricted for ethical purposes to those that excluded extreme or distressing images. In addition, the number of images was small (40 targets embedded in 40 distracters). Future studies of the effects of amygdala damage on memory for different 'categories' of emotion would benefit from the inclusion of more images in each category and perhaps a comparison between the extremes of valence and arousal rated images. In addition, as the International Affective Picture System increases in size, future studies will benefit from attempts to match images more closely in terms of the subject matter of each image so that perhaps, stimulus sets may be compiled that differ only in terms of rated valence and arousal elicited. The current study cannot rule out the subtle effects of other possibly confounding variables on memory performance (picture detail, lighting, exposure etc).

In addition, future studies of amygdala damage and memory for images would benefit from attempts to monitor physiological variables in response to image presentations and relate any physiological differences between patients and healthy controls. Some studies to date (e.g. Bechara et al., 1999) have indicated that reliable differences between controls and amygdala-damaged patients in Galvanic Skin

Response are evident in response to arousing stimuli. This poses interesting questions concerning laterality effects. It is possible that physiological differences may be evident in terms of the GSR response to stimuli produced by patients with bilateral damage that is more severe either in the right or the left hemisphere.

In addition, the present study has compared amygdala-damaged patients with a healthy control group. Future studies should compare patients with amygdala damage with patients who have undergone surgery to the brain that has not involved amygdala damage and a healthy control group that have undergone no surgical intervention. It is possible that surgical intervention itself affects affective states and that damage to the amygdala is coincidental in this response. Indeed, there is evidence that selective intervention in the left temporal lobe to control epilepsy may result in accentuated appropriate affective responses that are short lived (e.g. crying/psychogenic seizures – Luciano et al., 1993; Wang et al., 1995; Montenegro et al., 2000). Patients with selective amygdala damage are rare and patients who have undergone left temporal lobe surgery centered on the amygdala to control epilepsy may provide an important group of participants to assess the hypothesis in relation to emotional memory and the right hemisphere amygdala. It is clear that careful comparisons of neuropsychological function should be made between participants to avoid the possibility of confounding effects of non-specific emotional responses as a result of surgical intervention.

Finally, it is also important to reiterate the fact that the patients in this study did not have unilateral amygdala damage in either the left or the right hemisphere. Damage was bilateral in all participants. However, the consistent pattern in terms of

emotional memory impairment was, as predicted, most pronounced in the patient SE whose damage was more severe in the right hemisphere than in the left hemisphere. Further studies of patients with unilateral amygdala lesions should further delineate the role of the right hemisphere amygdala in emotional memory performance.

6.4.7. Summary of main findings

The present study has demonstrated that reliable lateralised differences in emotional memory performance have been identified when comparing two people with amygdala damage to the performance of controls over 4 tasks. While SE demonstrated more right than left hemisphere damage and DR demonstrated more left than right hemisphere damage both patients show evidence of bilateral damage to the amygdala. The present study has shown that:

1. Right amygdala damage is associated with a failure to show the heightened recognition memory scores for the middle, negatively valenced, emotive phase of a slide-story presentation. Left amygdala damage was associated with normal performance in this task.
2. Right amygdala damage was associated with a selective impairment in memory for negatively valenced emotional words compared to neutral words. Left amygdala damage was associated with normal performance in these tasks.
3. Right amygdala damage was associated with a tendency to take longer to respond correctly to low valence high arousal images, low valence low arousal images and high valence high arousal images relative to healthy controls. Left

amygdala damage was associated with normal performance on this task. The increase in recognition time associated with right amygdala damage relative to left hemisphere damage was reversed in response to neutral images.

4. Right hemisphere amygdala damage was associated with impaired overall picture recall performance relative to controls. Left hemisphere damage was associated with normal performance on this task. However, right amygdala damage was associated with a failure to recall any images that had been briefly presented to the right hemisphere.

Chapter Seven

General Discussion.

This thesis has reported a series of investigations of the relationship between physiological arousal, self-rated emotional arousal, and memory performance in human participants. It has investigated this relationship from a multidisciplinary perspective. Experimental chapters 2, 4 and 5 were psychophysiological investigations of the relationship between physiological arousal, self-rated arousal and memory in humans. Chapter 3 was a psychopharmacological investigation of the effects of noradrenaline re-uptake inhibition on memory for emotional material in humans. Finally, Chapter 6 was a neuropsychological investigation of the effects of lateralised amygdala damage on human emotional memory.

The first part of this chapter will summarize the specific findings of each experimental chapter and outline the ways in which these findings contribute to and extend the current literature. An attempt will then be made to outline the themes arising from these chapters, and the degree to which the chapters, taken as a whole, extend knowledge in the field of emotional memory research. The final part of this

chapter will outline cautionary notes and possible criticisms of the work reported in this thesis.

The first of the themes to be discussed in the second part of this chapter is best expressed by the question 'does it matter *how* we are aroused?' This theme assesses the contribution of subjective emotional arousal on one hand and physiological arousal on the other, in predicting human memory functioning. The second question concerns aspects of a to-be–remembered stimulus other than the emotional arousal it produces that may help determine the degree to which it will be remembered. The third question deals with possible underlying brain structures and neurotransmitter systems that may subserve emotional memory functioning in man.

The second part of this chapter deals with methodological considerations arising from the research with human participants as it applies to this thesis. Cautionary notes are outlined with respect to some of the stimuli employed in previous chapters, and methods of measuring memory and 'arousal' employed in previous chapters. On the basis of these methodological considerations, some suggestions are made for future research in the area of human emotional memory functioning.

7.1 Discussion of main experimental findings

7.1.1. Chapter 2:

Previous research has indicated that memory for emotional material but not neutral material may incubate over time (Kleinsmith & Kaplan, 1963, 1964;

Eysenck, 1977; Howarth, 1968; Magoun, 1963; Berlyne et al., 1965; McLean, 1969; Corteen, 1969; Maltzman et al., 1966; Schwartz 1974; Wesner, 1972; Howarth & Eysenck, 1968; Schwartz 1975; Hamilton et al., 1972; LaBar & Phelps, 1998). This 'incubation effect' translates into poorer memory for emotional material as compared to neutral material when assessed immediately after stimulus presentation, but better memory for emotional material than neutral material when assessed after a delay interval. The study reported in Chapter 2 investigated word memory performance over 4 time periods following presentation (immediate recall, 30 minute recall, 24 hour recall and 7 day recall) employing a within- participants design. Words presented for later recall were classified as emotional or neutral and matched for frequency of occurrence in the English language. 'Emotional' and 'neutral' words were defined in three ways; (a) Pre-defined, ('taboo' or 'neutral'), (b) according to whether participants produced above or below threshold verbal ratings of how emotionally aroused they felt when presented with words or (c) according to whether a subject produced an above or below threshold change in galvanic skin response from baseline at the time of word presentation. When words were matched for frequency of occurrence and pre-defined as either taboo or neutral (a), taboo words were consistently better remembered than neutral words over all time intervals (i.e. there was no evidence of incubation for emotional words). Using the second classification, emotional versus neutral words were matched for frequency of occurrence and defined according to whether participants produced above or below threshold verbal ratings of how emotionally aroused they felt when words were presented (b). Above threshold words were consistently more likely to

be recalled than neutral words with a pattern of decay occurring for both classes of words between the 24-hour memory test and the seven-day memory test (again, no evidence of an incubation effect). Finally, words were defined according to whether a subject produced an above or below threshold change in galvanic skin response from baseline at the time of word presentation (c). There was no significant difference between recall of above and below GSR threshold words over the 4 recall intervals. Furthermore, the expected pattern of decay occurred for all words such that more words were recalled at tests occurring within 24 hours of the presentation compared to the test occurring after seven days (again, no evidence of an incubation effect). Thus, using three different classification systems, no evidence was found to support the incubation effect.

Placed in the context of the existing literature, the current findings indicate that the strength of the incubation effect in human memory studies may owe more to the specific paradigms used rather than reflecting a true emotional memory incubation mechanism (e.g. 'reverberation' – Walker, 1958). The incubation effect in human memory is most apparent in paired associate learning and recall paradigms (Magoun, 1963; Berlyne et al., 1965; McLean, 1969; Kleinsmith & Kaplan, 1964; Kleinsmith and Kaplan 1963; Eysenck, 1977). Studies such as these demonstrate a reliable 'cross-over effect' in performance (see Figure 2.1) such that early memory assessment produces superior performance for low arousal items compared to high arousal items, and later memory assessments produce the opposite pattern (better memory performance for high arousal items). The effect becomes less pronounced

when free-recall of words is employed (Corteen, 1969; Maltzman et al., 1966; Schwartz 1974; Wesner, 1972; LaBar & Phelps, 1998).

The current study described in Chapter 2 has added to this literature by demonstrating that the incubation effect is not only reduced, but it is eliminated in studies which match to-be-remembered neutral and emotional words in terms of the frequency with which they occur in the English language. Furthermore, the incubation effect is not evident when words are classed as emotional or neutral by a variety of means (arbitrarily classified as 'taboo' or 'neutral', classified as above or below a verbal arousal rating threshold, or classified as above or below a mean GSR threshold). For each classification, participants showed evidence of a consistently superior pattern of memory for 'emotional' words compared to 'neutral' words. Participants tended also to show the normal pattern of memory decay over the recall intervals for both emotional and neutral words.

Attempts are beginning to be made to formulate models that explain the robust finding that emotional arousal influences long-term memory consolidation (Cahill, 2000; Cahill & McGaugh, 1990, 1998; McGaugh et al., 1994, 1996). The proposed models include reference to "reverberating circuits" which owe much to the Hebbian rule:

"When an axon of cell A is near enough to excite a cell B and repeatedly or persistently takes part in firing it, some growth process or metabolic change takes place in one or both cells such that A's efficiency, as one of the cells firing B is increased" (Hebb 1949)

Evidence to support the interpretation that reverberation occurs comes from emotional reactions following amygdala stimulation. These reactions generally appear gradually and dissipate slowly [as compared to the stimulation of the hypothalamus, for example, which results in rapid onset/dissipation of emotional responses (Zbrozna, 1972)]. This characteristic of the amygdala indicates that circuits within it may be capable of maintaining an excitatory state. Recently, Cahill (2000) has suggested that the amygdala may facilitate consolidation by interacting with peripheral adrenergic feedback. Implicit in his proposed model is that long-term memory modulation occurs via the modulation of the duration of reverberatory activity in what Cahill (2000) refers to as 'cortical-subcortical' loops. This model raises a series of testable hypotheses and constitutes an exciting synthesis of current neurobiological and behavioral evidence. Implicit in this model is the assertion that arousal consolidates memory perhaps via reverberation. Based on the research reported in Chapter 2 of this thesis, future attempts to test the hypothesis relating to reverberation should distinguish between consolidation and incubation. It would appear from the present study, that although arousal may consolidate memory (i.e. maintain superior performance for high arousal items for a period of time), it does not result in *incubation* per se (i.e. an *increase* in memory over time associated with high arousal items). Fundamental to the interpretation of results demonstrating incubation was that reverberating circuits might interfere with immediate recall for high arousal items but ensure better recall performance in the future (Kleinsmith & Kaplan 1963). The inference drawn from the current study is that, if reverberation

occurs at all for arousal inducing items, it does not appear, in itself to result in an improvement in memory performance for high arousal items over time.

7.1.2 Chapter 3

The animal literature and a growing body of human evidence implicate the central noradrenergic system in the process of memory modulation for emotional material. Blockade of the beta-adrenergic system in humans results in decreased recall and recognition memory performance, relative to placebo for elements of a series of slides accompanied by an emotional narrative. However, the role of the beta-adrenergic system in emotional memory functioning is far from clear. O'Carroll et al., (1999a) failed to demonstrate that beta blockade impairs emotional memory functioning. O'Carroll et al., (1999b) however, showed that stimulation of this system with yohimbine resulted in *increased* recall and recognition performance relative to placebo. These findings indicate that although the evidence in support of the role of the noradrenergic system in emotional memory functioning exists, the relationship between noradrenaline and emotional memory is not, as yet, clarified.

The study reported in Chapter 3 manipulated the central noradrenergic system in man using 4mg and 8mg doses of a new selective noradrenaline re-uptake inhibitor, reboxetine, in a double blind, randomized between group, placebo controlled design. It was hypothesized that noradrenergic re-uptake inhibition would

result in a dose dependent increase in free-recall and recognition memory performance, relative to placebo for emotionally arousing material.

The study found a dose dependent effect on recall and recognition scores *opposite* to the predicted direction (placebo> 4mg>8mg reboxetine). There were no significant differences between groups in self-rated stress and arousal scores or self-rated emotional reactions to the stimuli. Subjective self-ratings of arousal did not differ between groups when measured immediately following the presentation of the stimuli. The completion of the checklist at this time was approximately 10 minutes following peak plasma levels of the drug. Thus, the drug manipulation did not impair subjective arousal at the time encoding of the 'to-be-remembered' stimuli took place.

The finding of Chapter 2 supports an argument for subjective self-ratings of arousal at encoding being more predictive of later memory performance than physiological responses at encoding. The findings of Chapter 3 seem to demonstrate physiological differences between groups in terms of differences in levels of noradrenaline and heart rate but no differences in terms of subjective self- ratings between groups. However, the heart rate difference observed in this study was not in response to stimuli, the elevated levels of the drug were associated with the increased levels of heart rate response. Possible interpretations of this study are that the observed differences in memory scores for recognition between placebo and drug manipulation may have been due to an indirect pharmacological effect of the drug. It is possible for example that anticholinergic side effects of the drug manipulation interfered with encoding of the to-be-remembered stimuli.

An alternative explanation of the findings of Chapter 3 is that the dose regimen employed in the study was relatively high. The animal literature implicates the adrenergic system in arousal-mediated memory in a dose-dependent way; lower doses enhance and, typically, higher doses impair memory (Introini-Collison & McGaugh, 1986). It is possible therefore that both 4mg and 8mg of reboxetine may represent relatively high doses in studies of human memory for emotional material. This interpretation of the results is testable and it is suggested that further work is required to investigate the effects of noradrenaline re-uptake inhibition employing a wider dose regimen. For example, studies of the effects of reboxetine on psychomotor and cognitive performance in healthy adults have used a dose which is equivalent to half the recommended daily dose for depressed patients – i.e. 4mg (Kerr et al., 1996). The study reported in Chapter 3 indicated that doses equivalent to the starting daily dose (i.e. 8mg) might have impairing effects on memory functioning. A study comparing memory performance for the same slide stimulus materials using placebo, 0.5mg, 1mg and 4mg doses for example, could help clarify questions relating to dose dependency. In addition, the impairing effect of noradrenaline re-uptake inhibitors may be general and not restricted to emotional material. This hypothesis is testable using emotionally neutral stimuli.

Our results pose questions for theories that implicate increases in central noradrenergic tone as critical in the formation of memory for emotional material. The majority of studies published to date demonstrate the memory enhancing effects of stimulation and the impairing effect of blockade of the adrenergic system. Few studies have looked at the effects of selectively stimulating the central noradrenergic

system in man. O'Carroll and colleagues (1999b) found that 20 mg yohimbine hydrochloride increased recall and recognition scores for the slide presentation used in the study reported here relative to placebo (while blockade, using 50mg metoprolol impaired memory relative to placebo). Yohimbine hydrochloride acts to increase central noradrenergic activity via blockade of the α-2 adrenergic autoreceptor (Charney et al., 1987; Peskind et al., 1995). It is difficult to reconcile the opposing memory performance displayed by participants viewing the same stimulus material, in the same laboratory, but receiving either yohimbine (O'Carroll et al., 1999b) or reboxetine (Chapter 3). One would expect to see similarities in memory scores in the two studies if noradrenaline is critically involved in memory for emotional material. One possibility is that yohimbine is less selective than reboxetine and has effects on other neurotransmitter systems in addition to the noradrenergic system, (e.g. 5HT & dopamine – Den Boer & Westenberg, 1993) that may, in themselves, be influential in the processes involved in enhanced memory for emotional material. Other neurotransmitter systems and processes are known to be implicated in memory modulation for emotional events. These include a number of different stress hormones including the opioid peptidergic and GABAergic systems (McGaugh 1993) and the hypothalamic-pituitary-adrenal axis (Yehuda and Harvey, 1997). Therefore, a further possible interpretation of the current finding with reboxetine is that other neurotransmitter systems either independently, or interacting with the noradrenergic system, modulate memory for emotional material in man.

The research reported in Chapter 3 was stimulated by the established body of animal evidence that indicates that stimulating the hormonal and neurotransmitter

responses that occur at the time of stressful stimulation results in memory modulation (for reviews see McGaugh, 1992; 2000; Cahill, 2000). The study reported in Chapter 3 extends the current research field assessing the neurobiology of emotional memory functioning in humans. It has been the first *direct* investigation of the role of noradrenaline in human emotional memory functioning and therefore allows more direct conclusions to be drawn concerning the role of noradrenaline in human emotional memory. The study suggests that the role of the noradrenergic system in human emotional memory functioning is a complex one. On the surface it would appear from the present results (Chapter 3) that reboxetine impairs memory in participants employing 4mg and 8mg doses of the selective noradrenaline re-uptake inhibitor, reboxetine. The current finding implies that either noradrenaline does not improve memory functioning, or that the relationship between noradrenaline and emotional memory functioning is more complex. It is suggested that, due to the wealth of animal and growing body of human evidence, the conclusion that this neurotransmitter is not involved in emotional memory functioning cannot be drawn based on the current study alone. It is more reasonable to suggest that the current study be replicated and extended in the future. One suggestion is that the effects of different doses of this particular pharmacological manipulation on human emotional memory functioning should be investigated and that smaller doses of reboxetine may enhance memory for emotional material in man. Another explanation of the memory effects observed in this study is that, contrary to expectations, reboxetine produced anticholinergic side effects which

interfered with any potential memory enhancing effect of noradrenaline re-uptake inhibition.

7.1.3. Chapter 4.

Intense emotional events lead to an increase in subjective and physiological arousal and such events tend to be well remembered. However, little is known of the relative contributions of subjective (self-rated) as opposed to physiological responses in determining memory performance. If physiological responses predict memory performance, then reliable differences in memory should be evident between participants who demonstrate differences in physiological 'reactivity' to 'to-be-remembered' stimuli. One such group who demonstrate decreased physiological reactivity compared to normal participants are 'alexithymics'. Alexithymia is a term used to describe a 'cognitive affective style' in healthy people characterized by an inability to describe or access emotional feelings. Chapter 4 reported the results of a study comparing the physiological variables of blood pressure and heart rate during baseline relaxation periods and in response to a series of emotional and neutral slides in participants producing extreme scores on a questionnaire measuring the construct of alexithymia. High alexithymics and low alexithymics produced equivalent self-ratings of emotional arousal in response to a series of slides depicting an emotional story. They differed on one physiological measure recorded in the laboratory. High alexithymics produced lower levels of

physiological reactivity as expressed by the change (decrease) from heart rate relaxation period during slide presentation compared to low alexithymics. However, there were no significant differences between the groups when memory for the stimuli was assessed at a surprise memory assessment following a seven-day delay.

Measuring the memory performance of participants who were classified as high or low alexithymics provided an opportunity to compare the memory performance of participants who, according to the literature, should show evidence of differences in physiological responding to to-be-remembered stimuli. Furthermore, in accordance with the literature, these participants were expected to demonstrate no differences in their subjective emotional response to the stimulus materials compared to low alexithymics. Therefore, studying the memory performance of this group provided an opportunity to compare the role of subjective responses to stimuli with physiological responses to stimuli in influencing subsequent memory for emotional material in humans. The study of memory in alexithymia, as a means of assessing differences in emotional processing, has been proposed by the authors of the Toronto Alexithymia Scale (Bagby et al., 1994).

The prediction, based on the results of Chapter 2, was that differences in subjective rather than physiological responses would be the best 'predictors' of differences in emotional memory functioning. This prediction was supported in Chapter 4. No differences were evident in memory performance when comparing the high and low alexithymics. In addition, subjective responses in the high alexithymia group did not differ from the low alexithymia group. However, high alexithymics displayed reduced heart rate reactivity to 'to-be-remembered stimuli' compared to

the low alexithymics. Therefore, differences in physiological reactivity did not appear to predict memory performance.

The study extends the literature in two ways. In the first instance, the results of this study provide further support for the hypothesis that alexithymia is characterized by differences in physiological responses compared to normal participants (Hyer et al., 1990, Nemiah et al., 1977; Wehmer et al., 1995). In the second instance, this study has, for the first time, investigated a specific hypothesis relating to the emotional memory performance of high alexithymics. The study reported in Chapter 4 found that, although high alexithymics produce lower levels of physiological reactivity than low alexithymics, this difference in physiological response to to-be-remembered stimuli did not translate into differences in neutral or emotional memory performance. It is clear that human emotional reactions to stimuli presented in the laboratory may be more complex to study than the emotional responses of animals. Nevertheless, any conclusion relating to emotional arousal and memory must measure the emotional arousal responses in participants. It is suggested here that both physiological reactions at the time of the presentation of to be remembered stimuli and self-rated emotional reactions to those same stimuli provide potentially reliable means of assessing the degree to which an emotional reaction to a stimulus predicts memory for that stimulus.

In Chapter 2 of this thesis attempts were made to compare the memory performance of participants for words classified in terms of self-rated reactions, pre-defined and classified in terms of physiological responses and where possible this approach is utilized throughout this thesis. In Chapter 4, attempts were made to

distinguish between the effects of subjective self –rated emotional reactions and physiological reactions on memory performance. This was done in an attempt to test directly the effects of physiological arousal alone on memory performance. It is possible to argue that declarative memory formation in humans depends on conscious encoding of the to-be–remembered stimulus. Models of memory performance in humans based on animal research indicate that while classical conditioning may occur at the levels of sub-cortical structures, conscious cortical routes to memory storage may be modulated by sub-cortical structures involved in conditioned emotional responses (McGaugh, 1993, LeDoux, 1994). As outlined above, McGaugh and colleagues have developed models that suggest that structures in the human brain involved in classical conditioning of emotional responses may also have a time limited role in human declarative memory. On this account, it would appear that declarative memory mechanisms, while dependent to a certain degree on the time limited involvement of structures regulating the autonomic nervous system, may also depend on a conscious subjective emotional reaction. Such a self-rated emotional reaction may therefore predict *declarative* memory for emotional material more reliably than physiological responses to that same material in healthy adult human participants.

7.1.4. Chapter 5

The study of human emotional memory performance requires an understanding of the effects of factors other than emotion on memory functioning.

For example, it is possible to argue that factors other than emotional arousal exert their effects on memory independently of or in interaction with arousal. One of these 'other factors' is the unusualness or distinctiveness of the emotional stimulus. Psychological studies of human memory for emotional material have highlighted the importance of measuring the variable of 'unusualness' in studies of emotional memory functioning. For example, Christianson & Loftus (1991) demonstrated that memory for the central elements of emotional visual material, (a road traffic accident) was superior to that of peripheral material. In the 'unusual' condition, the stimuli employed depicted a road traffic scenario. The female victim of the road traffic accident in the unusual condition was carrying her bicycle in the middle of the road rather than lying, injured, beside it (as in the emotional version). Participants' memory for the central and peripheral details in the unusual condition did not differ, whereas in the emotional condition, memory for the central elements was superior.

Previous research with animals indicates that neural mechanisms may exist that alert an organism to unusual stimuli in potentially threatening situations. For example, auditory responsive cells in the lateral nucleus of the amygdala, itself connected to the basolateral nucleus involved in the regulation of the human autonomic nervous system response to threat, can be divided into cells that are either habituating or consistently responsive to sound (Bordi & LeDoux, 1992). It has been suggested (LeDoux 1996) that cells habituating to sound in the amygdala could 'permit' the amygdala to ignore a stimulus once it became familiar. It has also been suggested that sound and shock pairing at these cells in the amygdala (Romanski et al., 1993), might reduce habituation 'allowing' the cells to respond to rather than

ignore significant, unexpected stimuli. These same structures may have a time-limited role in memory formation for the stimuli that initiate an emotional response (as suggested by Cahill et al., 1998).

These observations in the literature led to the hypothesis that stimuli that could be defined as 'unexpected' or 'incongruent' would be remembered better than stimuli that could be defined as expected. Moreover, stimuli that were not only incongruent but also rated as unpleasant in nature would not only elicit a greater arousal response (physiological and subjective) but would be remembered better than congruent or expected stimuli.

The between- participants study reported in Chapter 5 tested long- term recognition and recall memory for visual and auditory stimuli that were combined either (a) congruently or (b) incongruently. In addition, these congruent or incongruent stimuli had been categorized as either low valence high arousal, low valence low arousal, neutral, high valence low arousal or high valence high arousal. Participants who had been presented with incongruent combinations of sounds and images recalled significantly more images at a one- week surprise free-recall test than participants who had been presented with congruent sounds and images. However, most images were recalled from the low valence, high arousal category (i.e. rated as the least pleasant and most arousing) regardless of 'unusualness' (i.e. there were no significant differences between congruent and incongruent groups for this category). This study also demonstrated that expected significant differences existed between categories and groups in terms of subjective self-ratings of how pleasant (valence) and how arousing participants found depicted images. This was

not mirrored by significant between- group differences in physiological responses such as GSR and heart rate in response to the presentations. Therefore differences in memory performance were evident in the absence of differences in physiological responses at encoding but in the presence of differences in subjective valence and arousal ratings.

This finding extends current knowledge in two ways. In the first instance it complements and supports the results of Chapter 2 by demonstrating that the subjective emotional responses of healthy participants to stimuli (be they images or words) in the laboratory are more predictive of later memory performance than the physiological arousal responses to those same stimuli. In Chapter 5, physiological variables such as GSR and heart rate in response to image and sound pairings at encoding did not predict later memory performance, but self –ratings of emotional reaction to the stimuli did predict later memory performance.

In the second instance, the findings of Chapter 5 extend our understanding of the impact on memory of different kinds of emotional subjective response to stimuli. The literature on emotion appears to polarize. Some theories suggest that emotion is best understood in terms of discreet categories like 'fear' 'anger' and 'disgust' for example (Ekman, 1972, 1982; Izard, 1971; Calder et al., 1996). Others view emotion in terms of a continuum of certain dimensions such as 'valence' and 'arousal' (Russell, 1980; Tellegen, 1985; Lang et al., 1990; Bradley et al., 1992). In terms of memory performance, a recent Positron Emission Tomography (PET) activation study of the healthy amygdala has raised questions for theories linking this structure with the recognition of 'fear' specifically. For example, Hamann et al., (1999) found

that amygdala activation related to enhanced memory for arousing stimuli regardless of the stimulus valence (i.e. for both positive and negative material). This suggests that structures in the brain may be more involved in arousal-mediated processes in general rather than in discrete categories of emotion. The present study employed a series of stimulus categories that had been constructed by varying the dimensions of arousal and of valence. The results did not support the dimensional approach to emotion in terms of memory functioning. The dimensional approach would have predicted that high levels of arousal associated with stimuli (whether the stimuli were positive or negative in terms of valence) would be predictive of heightened recall performance. Participants rated two of the categories similarly in terms of the degree of arousal they felt when viewing the stimuli. These categories were both high arousal categories. However, one category was pleasant (high valence) the other category was unpleasant (low valence). Free-recall memory performance was superior for the low valence, high arousal category compared to the high valence, high arousal category and it made no difference if the stimuli in these categories were unusual. This finding suggests that emotional memory functioning in healthy adults appears to be category specific because if the dimension of arousal itself is an important predictor of memory functioning, all stimuli that receive high arousal ratings should be well remembered. The study reported in Chapter 3 found that it was the *interaction* of low levels of rated valence and high levels of rated arousal that corresponded with improved declarative free-recall performance. It is arguably the case that unpleasant highly arousing categories are remembered better because of the implications these categories have in terms of survival. So, for example, in

evolutionary terms it may be more important in terms of survival to remember an unpleasant, highly arousing experience than a pleasant highly arousing experience.

7.1.5. Chapter 6

Single case studies of humans with selective bilateral amygdala damage demonstrate an apparent impairment in these participants' recognition memory performance for emotional but not neutral material. In healthy individuals the activation of the right amygdala at encoding is correlated with recall of emotional but not neutral material (Cahill et al., 1996). The study reported in Chapter 6 investigated the differential effects of amygdala damage in the left or the right hemisphere on emotional memory functioning. The study included a patient with amygdala damage more severe in the left hemisphere than the right (DR), and a patient whose damage was more severe in the right than in the left hemisphere (SE). Both these patients' performance on a series of four tasks was compared to the performance of healthy age, IQ, education and neutral memory matched controls. Results indicated that, in the first instance, right amygdala damage was associated with a failure to show the normal heightened recognition memory scores for the middle, negatively valenced, emotive phase compared to the first and third phases of the Cahill slide story presentation. Left amygdala damage was associated with normal performance on this task. In the second instance, right amygdala damage was associated with a selective impairment in memory for negatively valenced emotional words compared to neutral words. Left amygdala damage was associated with

normal performance on both these tasks. In the third instance, right amygdala damage was associated with a tendency to take longer to respond correctly to low valence high arousal images, low valence low arousal images and high valence high arousal images compared with healthy controls. Left amygdala damage corresponded with normal performance on this task. The increase in recognition time associated with right amygdala damage relative to left hemisphere damage was reversed in response to neutral images. In the fourth instance, right hemisphere amygdala damage was associated with a failure to recall any images presented to the right hemisphere. Left amygdala damage coincided with a tendency to recall a similar number of images presented to the right hemisphere as healthy controls.

Placed in the context of the current literature, the finding of the current study supports the body of literature that implicates the human amygdala in declarative emotional memory functioning (e.g. Adolphs, 1999; Babinsky et al., 1993; Markowitsch et al., 1994; Cahill et al., 1995; Phelps et al., 1998). Furthermore, it extends the literature by demonstrating that amygdala damage that is more severe in the right than the left is associated with an emotional memory impairment for both images and words. In addition, left amygdala damage was found to be associated with relatively normal performance. This finding supports the hypothesis that the right amygdala is critically involved in the formation of memories for emotional material in man. Right hemisphere involvement in functions related to emotion has been addressed in the past using a wide range of methodologically diverse studies of un-impaired, brain lesioned and mood-disordered populations (Silberman & Weingartner 1986). These studies imply a role for the right hemisphere generally in

functions relating to predominantly negative emotions. Brain activation studies of PTSD sufferers (Rauch et al., 1996) and healthy adults (Cahill et al., 1996) demonstrate that right amygdala activation more so than left amygdala activation is associated with viewing emotional images. Moreover, it is right amygdala activation and not left amygdala activation that correlates with and predicts later recall of the emotional information (Cahill et al., 1996).

The current study complements the findings with healthy adults by demonstrating that damage to the right hemisphere amygdala results in an emotional memory impairment while damage to the left hemisphere amygdala is associated with normal performance.

Although the study reported in Chapter 6 supports the hypothesis that the right hemisphere amygdala is critical for declarative emotional memory functioning, it is far from conclusive. The patients used in the study reported in Chapter 6 both had some degree of bilateral damage. SE's damage was more severe in the right hemisphere, DR's damage was more severe in the left hemisphere, but nevertheless both patients had damage in both hemispheres. Furthermore, the damage in both patients was not confined to the amygdala. Future work should capitalize on patients who have undergone more selective surgery that is (a) lateralized and (b) confined only to the amygdala, however, such patients are extremely rare. Furthermore, it essential that future work should compare groups of patients defined by the side of damage. One clear possibility of this study is that SE, with his right hemisphere amygdala damage and impaired emotional memory functioning is idiosyncratic.

7.2. Themes

7.2.1 Theme 1: Does it matter how we are aroused? What is the relationship between subjective emotional reactions, physiological arousal and subsequent memory?

There have been two divergent views evident in past research concerning the nature of arousal and memory for emotional events in man. One view is that arousal is a unitary process characterized by the "excitation of the individual as a whole" (Duffy, 1963 – p3). The other view is that arousal is a more complex multidimensional process with behavioural, cognitive as well as physiological elements (Lacey, 1967).

The view that arousal has non-specific properties may account for the findings of the effects of arousal on performance in the animal literature. These findings have been found to support an inverted U-form curve relationship between arousal in general and performance, with extreme levels of arousal having the most detrimental effects on memory performance.

At an intuitive level, the view that arousal is a more complex multidimensional process would seem to be a more encompassing explanation of the human experience of arousal. High levels of arousal do not always coincide with poorer performance in the human literature as reviewed in the introduction of this thesis. Therefore, the inverted U-form relationship found between arousal and performance with animals may not easily be mapped on to the relationship between

arousal and memory performance in humans. Broadbent (1971) attempted to operationally separate various indices of arousal into those that are psychological and those that are physiological and this approach adopted in human research on the relationship between memory and arousal has allowed useful empirical investigations of the role played by different types of arousal (i.e. physiological versus emotional – Libkuman et al., 1999). Evidence exists to support this multidimensional interpretation of human arousal. For example, extensive work carried out by Antonio Damasio and colleagues has highlighted dissociations between subjective and physiological responses in the context of choosing between advantageous and disadvantageous consequences of action (Damasio, 1996). The human experience of arousal clearly has many physiological as well as psychological components.

The neurobiological literature would suggest that the physiological response to threat may involve direct routes to brain structures, which activate autonomic nervous system responses with conscious appraisal coming somewhat later (e.g. thalamic – amygdala pathways described as 'quick and dirty' mechanisms whereby an organism can avoid immediate threat - LeDoux, 1996). Equally, however, the conscious appraisal that may follow the response to possible danger is equally as important in either maintaining or terminating a 'quick and dirty' response. It would seem therefore that both the physiological and psychological components of the human emotional experience as they relate to memory provide justifiable routes for empirical investigation.

The study reported in Chapter 5 of this thesis found that different 'between-category' *subjective* emotional reactions to stimuli (as evidenced by verbal or written self-report following stimulus presentation), coincided with between category differences in subsequent memory performance. The study demonstrated that significant differences existed between categories and groups in terms of subjective self-ratings of how pleasant (valence) and how arousing participants found depicted images. The least pleasant (low valence) and most arousing of the categories as evidenced by subject ratings were remembered best in free-recall assessments following a one week interval, more so than categories that were considered equally as arousing but pleasant (high valence). This was *not* mirrored by significant between group differences in physiological responses such as GSR and heart rate in response to the different categories of stimuli. Therefore differences in memory performance were evident in the absence of differences in physiological responses but in the presence of differences in subjective valence and arousal ratings. Chapter 2 of this thesis employed different stimuli (i.e. neutral and taboo word classes). It was demonstrated that while self-ratings of arousal in response to words reliably differentiated high and low arousal words in terms of memory performance, this was not evident when words were classified in terms of whether they were associated at presentation with above or below threshold GSR responses. Again, this would indicate that self ratings of emotional arousal rather than physiological arousal reliably predict memory performance with stimuli rated as emotionally arousing being better remembered than stimuli rated as not emotionally arousing. However, it should be noted that either more extreme emotionally arousing

stimuli or more sensitive recording methods for the physiological indices studied may indicate different relationships between emotional responses and memory in other contexts.

In Chapter 4 evidence was found for a difference in physiological response to 'to-be-remembered' stimuli between two groups differing on a measure of personality. The difference in heart rate reactivity, (with high alexithymics producing lower levels of reactivity compared to low alexithymics), did not correspond with any differences in memory performance. It was predicted that higher levels of physiological reactivity to stimuli may coincide with better memory for those stimuli but this did not occur. Interestingly, there were no between-group differences in subjective self-ratings of how emotionally arousing the 'to-be-remembered' stimuli had been found when assessed after stimulus presentation. This finding, in addition to the findings of Chapters 2 and 5 would seem to indicate that memory performance for stimuli and subjective self ratings for the same stimuli seem to vary together whereas physiological responses and memory performance do not appear to vary together. This indicates that self-rated emotional reactions to the stimuli employed in Chapters 2, 3 and 4 of this thesis were more predictive of memory performance than physiological reactions to those stimuli.

Chapter 6 of this thesis investigated the role of amygdala damage on memory for emotional material. Specifically, hypotheses were tested relating to the role of the left AC and the right AC in emotional memory performance. No direct measurement of the physiological responses of these patients was made in the current work due mainly to constraints of testing in the patients' own homes.

However, previous studies (Adolphs 1999; Phelps et al., 1998) have demonstrated that patients with bilateral damage to the amygdala fail to show conditioning of autonomic physiological responses to aversive stimuli. In the presence of wide-ranging emotional memory impairment, studies have also demonstrated that patients with amygdala damage show a relatively normal subjective and/or physiological response to the stimuli presented. This normal response occurs alongside impaired declarative memory for those stimuli (Cahill et al., 1995; Adolphs et al., 1997; Hamman et al., 1997). This finding indicates that the amygdala may not be necessary for subjective emotional responses per se but may be responsible for translating an enhanced emotional reaction (be it physiological and/or subjective) into improved memory performance. The study reported in Chapter 6 demonstrated that while some emotional reactions following amygdala damage appeared normal (i.e. the self rating of valence/pleasantness of stimuli), other subjective responses were disrupted relative to healthy controls (i.e. ratings of *arousal* only). This finding held regardless of the hemisphere of amygdala damage. For example, both the patients, the patient with damage more severe in the left amygdala and the patient with damage to the right amygdala rated the arousal value of images presented in the study in an idiosyncratic manner (but not significantly different from controls). This would seem to implicate the amygdala bilaterally in subjective emotional responses of arousal to stimuli but the right amygdala specifically in memory performance for those same stimuli. This interpretation does not suggest that the amygdala is not involved in translating an emotional response into improved memory, rather it suggests that the amygdala, bilaterally, perhaps is involved in certain kinds of

emotional responses to stimuli (i.e. arousal responses). The right amygdala specifically may be involved in translating those responses into improved memory. A testable hypothesis is generated by this interpretation. Other patients with right amygdala damage should show impairments in both subjective ratings of arousal in response to stimuli and memory for those same stimuli. Patients with left amygdala damage should show impaired subjective ratings of arousal to stimuli but no impairment in memory for those same stimuli. This hypothesis was generated by the results of the study reported in Chapter 6 and depends on the interpretation of arousal ratings as idiosyncratic rather than significantly different from the ratings of controls. However, additional studies employing different stimulus materials in participants with strictly lateralized damage are needed to provide further support for the proposal that the right amygdala translates an emotional reaction into heightened memory for the source of that emotional reaction.

It is important to state that the findings of Chapters 2, 3, 4, 5 and 6 do not necessarily support the interpretation that physiological arousal does not influence memory. In the first instance the arousal inducing stimuli used in this thesis, while demonstrably eliciting differences in physiological and subjective arousal in previous studies, were not necessarily similar to the kinds of stimuli that elicit high levels of arousal in everyday life. There are clear ethical constraints on the exposure of healthy human participants to extremely negative emotional images in the laboratory. It is clear that severe trauma instigates physiological responses that may well have different influences on memory performance (e.g. in PTSD irregularities in the hypothalamic – pituitary-adrenal axes have been implicated in the abnormal

emotional response to stress. The failure to mount an appropriate cortisol related attenuation of physiological arousal has also been implicated in the process of forming intrusive emotional memories – Yehuda & Harvey, 1997). However, the ethical constraints under which human research on emotional memory must operate determines that the studies reported in this thesis limit conclusions drawn to those relating to mild physiological and emotional responses in the laboratory.

In the second instance it would appear that a multidimensional interpretation of human arousal would predict that arousal *does* affect memory but that only certain types of arousal affect memory, namely arousal (be it emotional or physiological) that is elicited by the to-be-remembered stimulus. Libkuman and colleagues (1999) provided a demonstration of the differential effects of arousal as defined as either emotional or physiological. They found an improvement in both central and background detail memory for the slides accompanied by a story that was emotional in nature compared to the story that was neutral in nature. This study outlines the qualitative difference in the type of arousal evident in studies of human emotional memory. Libkuman et al., interpreted differences in memory scores between participants viewing the story with emotional content and participants viewing the story with relatively neutral content as evidence of an effect of emotional 'arousal' on memory. Importantly, the effect of emotional arousal was established in the absence of any physiological measure of emotional arousal. In the light of these findings, it is possible to argue that the stimuli employed in the studies reported in Chapters 2, and 3 of this thesis elicited reliable differences in 'emotional/subjective arousal'. Emotional arousal may be represented by differences

in verbal self-ratings of emotional arousal in Chapter 2 and written self-ratings of valence and arousal in Chapter 3. Therefore, it may be possible to conclude with respect to the findings reported in this thesis, that subjective emotional arousal related to reliable differences in memory while physiological arousal related to no such difference in memory. Specifically, high ratings of emotional arousal related to superior memory performance for the rated stimuli compared to low self-ratings of emotional arousal in Chapter 2. In addition, low self-ratings of valence (pleasantness) and high self-ratings of arousal lead to superior memory performance compared to other categories (LVLA; N; HVLA; HVHA) as demonstrated in Chapter 3.

However, it is clear that the method of eliciting physiological arousal in the Libkuman et al., study (1999) differed from the method of eliciting physiological arousal in the studies reported in Chapters 2, 3, 4, and 5 of this thesis. The participants in the Libkuman et al., study performed physical exercise, resulting in observable differences between exercise and no exercise participants in levels of 'free floating' physiological arousal. In the studies reported in chapters of this thesis, levels of physiological arousal (GSR, ECG, blood pressure) where monitored during stimulus presentation. It is arguably the case that the physiological arousal observed in the chapters of this thesis was more 'source linked' than the physiological arousal observed in studies where participants perform exercise. It is reasonable to suggest that the term 'emotional arousal' should differentiate between both self-rated feelings of emotional arousal in response to stimuli and the physiological change with respect to baseline observed when the stimuli are presented. The studies

reported in Chapters 2, 4 and 5 of this thesis indicate that self-ratings of emotional arousal predict memory performance while physiological indices of arousal in response to the to-be-remembered stimuli do not predict memory performance. The studies in this thesis where only mild or no physiological responses were observed in response to the stimuli provide equivocal evidence concerning the relationship between physiological arousal and subsequent memory. The physiological arousal (heart rate) observed in the study reported in Chapter 3 did not significantly differ between groups receiving the drug or placebo (after covariation for baseline differences in blood pressure). In effect, a difference in memory was evident in the absence of differences in either subjective or physiological arousal but in the presence of difference levels of central noradrenaline levels. The administration of a selective noradrenaline re-uptake inhibitor (and its possible anticholinergic effects) may have obscured any usual relationship between subjective arousal and memory performance.

7.2.2. Theme 2: Is it arousal that affects memory for emotional material or something else? A consideration of the affects of distinctiveness and attention.

The results of Chapter 5 extend our understanding of emotional memory by increasing our knowledge of the ways in which stimulus characteristics interact with emotional arousal. It is clear that the processes involved in the formation of emotional memories are not necessarily equivalent to the processes involved in the formation of memories for neutral events (Packard et al., 1994). For an event to be

classed as emotional requires some evidence to indicate that subjective or physiological levels of arousal increase in response to the presentation of that stimulus. However, the fact that subjective and or physiological arousal increases as a result of the presentation of a stimulus does not necessarily lead to the conclusion that it is arousal *per se* that leads to memory modulation. It is possible that something else inherent in a stimulus (e.g. its distinctiveness/unusualness or the attention it receives from the perceiver) other than its 'emotionality' has an effect on memory independently of, or as a result of interactions with arousal.

There are two possible approaches to be taken to the consideration of factors other than arousal in memory modulation. One approach is to maintain that the existence of other factors, be they stimulus related or response related, weaken any argument for a special effect of emotion on memory. The other approach that could be taken is that factors other than emotional arousal can be considered an intimate part of an emotional reaction to a given stimulus and should be isolated and studied as elements of emotional memory functioning.

7.2.2.1. The distinctiveness of an arousal inducing stimulus

It is possible to argue that the memory advantage seen for emotional arousing stimuli is due in part to the fact that emotional events are likely to be more unusual than neutral events. At an intuitive level it is part of an emotional experience that the experience is surprising. The example used in Chapter 1 of this thesis was of viewing a poisonous snake at close range behind glass in the reptile house of a zoo,

or seeing it coiled in the grass at close range while walking in the open. The fact that a stimulus is unique, distinct or unexpected could account for the memory advantage with arousal essentially an 'epiphenomenon'. Alternatively, the distinctiveness of a stimulus may trigger an arousal response. Distinctiveness itself may not affect memory but it may initiate the physiological processes that do affect memory. From weapons focus studies it would appear that the 'weapons focus effect' seen in eyewitness memory performance (see Chapter 1) may be evident for unexpected non-emotional items substituted for the weapon (Kramer et al., 1990, Loftus et al., 1987). This would provide support for the possibility that unusualness plays a role in memory formation. In addition, experiments in which participants' eye movements are monitored suggest that fixations are made for longer durations and more often when objects are unusual (Loftus & Mackworth, 1978). Alternatively, when to-be-remembered stimuli are manipulated to provide visual images that are either emotionally arousing or unusual, but are similar in other respects, memory has been found to be superior for the central details of the emotional compared to the unusual image (Christianson & Loftus, 1991; Christianson et al., 1991).

The studies reported in Chapters 2 and 5 of this thesis have investigated the effects of arousal on memory while taking distinctiveness into account. In Chapter 2, words used in the study were matched for frequency of occurrence in the English language. It is possible to suggest that arbitrarily classified 'taboo' words are likely to be remembered more readily than neutral words. This may simply be because they belong to a smaller 'category' of words in the English language and are therefore more unusual, distinctive and less likely to be confused with other words in recall.

The study described in Chapter 2 essentially compared memory for taboo words and distinctive neutral words that occurred as frequently as the taboo words in spoken and written English. If the beneficial memory effect for taboo words is related to the fact that taboo words are just more distinctive than neutral words, then no differences should be evident in memory performance for words matched in terms of frequency of occurrence. The study reported in Chapter 2 found that when the word set was rated in terms of emotional arousal produced when reading the words, words that received a higher rating coincided with words that were considered taboo. This is not surprising in itself. However, memory performance was consistently superior for words rated as high arousal or words pre-classified as taboo as compared to words classified as low arousal or neutral. This finding suggests that the self-rated arousal response to word presentations is critical in terms of predicting later memory performance and not the degree to which the words are distinctive. The study in Chapter 2 suggests that a neutral word may be just as distinctive as an emotional word and yet still be remembered poorly compared to the emotional word. This finding provides support for the suggestion that emotion affects memory over and above any concomitant effect of distinctiveness on memory.

The study reported in Chapter 5 of this thesis addressed the question of the roles played by distinctiveness and emotion in memory modulation. The aim of this study was to produce a series of stimuli that could be classified as congruent or incongruent and then assess the degree to which varying the emotional quality of these stimuli would affect memory performance. A distinctive or 'congruent' stimulus was an image presented with a sound that 'matched' the subject matter of

the image. An incongruent stimulus was an image presented with a sound that did not match the subject matter of the image. In effect, in Chapter 2, it had been demonstrated that emotion exerted its effects on memory out-with any effects of distinctiveness, i.e. that the effects of emotion on memory could not be explained by claiming that the emotional stimuli were more distinctive. In Chapter 5 we demonstrated that distinctiveness *could* however play a part in affecting emotional memory formation. There were two main findings of the study. In the first instance, participants who viewed and rated incongruent combinations of sounds and images remembered more images in a surprise free-recall assessment made after 7 days than participants who viewed congruent combinations. In the second instance participants remembered more images from the category they had rated as least pleasant (low valence) and highly arousing (high arousal). However, identical incongruent low valence high arousal images were not remembered significantly better than congruent low valence high arousal images. This finding suggests that low valence, high arousal categories were best remembered regardless of whether identical images were 'made' congruent or incongruent. In other words, the present study demonstrates that valence and arousal influence memory regardless of distinctiveness.

The interpretation placed on these findings is that distinctiveness is often an inherent part of a stimulus that leads to an emotional response to that stimulus. Physiological evidence outlined in Chapter 5 of this thesis on the changes that occur during learning in animals implicate the notion of stimulus incongruence as critical in the process of emotional reactions to potentially dangerous stimuli. Joseph Le

Doux and colleagues have demonstrated that the same cells in the lateral nucleus of the rat amygdala respond to both shock and sound stimuli (Le Doux, 1994). In addition, of the cells stimulated by sound, some have been found to habituate to sound presentations and others are consistently responsive. The notion of cells that habituate to sound implicate mechanisms at the cellular level that may respond to auditory stimuli that are unusual, different or new. The fact that this mechanism may exist in an area of the brain intimately linked with the regulation of the autonomic nervous system leads to the possibility that incongruent sounds are detected by the amygdala in order to instigate the physiological changes that underpin avoidance behaviors to potential threat. The time- limited role of the amygdala in influencing memory storage in other brain areas has been documented (Packard et al., 1994) and has implications for the enhanced storage of incongruent stimuli that are emotionally arousing in nature.

7.2.2.2. The effects of attentional processes on memory

The position that arousal improves memory for central but not for peripheral detail is based on the Easterbrook hypothesis (1959) which suggests that arousal narrows the focus of attention allowing an organism to focus on the most salient cues in the environment. It is clear that the attention devoted to a stimulus may have effects on memory functioning out-with, or as the result of an interaction with arousal. It is possible to claim that emotional memory effects may, in fact be due to the effects of attention. Attentional differences may determine differences in

memory and not differences in emotional arousal. Studies of the effects on memory of attentional processes appear to have used arbitrarily defined 'emotional' and 'neutral' to-be-remembered stimuli. The Easterbrook hypothesis has been used to explain the weapons focus effect for example, where by the weapon in a violent or arousing scenario is described in great detail at the expense of descriptions of the perpetrator or other aspects of the event. The research suggesting that emotion benefits central but not peripheral detail is limited by the fact that definitions of what is central and what is peripheral differ in different studies.

One possibility is that studies reporting the beneficial effects of emotion on memory assess memory for central details and studies reporting detrimental effects of emotion on memory assess memory for peripheral details. The current work contributes to the issue of central and peripheral details in two ways. In the first instance, Chapter 5 of this thesis suggests, in line with the Easterbrook hypothesis, that not all highly arousing stimuli are well remembered. A visual stimulus that has been rated as unpleasant (low valence) and highly arousing is more likely to be remembered than a stimulus that has been rated as pleasant (high valence) and highly arousing. An added interpretation arising from this thesis is that some cues in the environment are more salient for survival than others and that, in the event of threat, attention will be focused in terms of stimuli that are most salient for survival. It would appear that *unpleasant arousal* (represented by a subjective response in terms of valence and arousal) in response to a stimulus may have more implications in terms of immediate survival responses with respect to that stimulus than *pleasant arousal*.

As outlined in the introduction, an alternative to the suggestion that arousal selectively narrows the focus of attention thereby benefiting later memory for central rather than peripheral details is the suggestion that arousal benefits memory in general. Flashbulb memories (Brown & Kulik, 1977) are believed to include complete photographic like detail [another analogy is the neurophysiological 'now print' response outlined by Livingston (1967)]. This detail translates into enhanced memory for *both* the central and peripheral elements of the to-be –remembered stimulus.

The results reported in this thesis do not appear to support the suggestion that high levels of arousal always correspond with better memory performance compared to lower levels of arousal. Although the thrust of flashbulb theories seems to be that high arousal corresponds with a permanent record of all available information, it would seem fair to suggest that flashbulb theory would support the prediction that arousal should predict better memory performance compared to low arousal.

Evidence favouring the flashbulb theory of emotional memory formation comes from diverse sources (Bohannon, 1988; Christianson, 1989; Heuer & Reisberg, 1990; Libkuman et al., 1999). However it is clear that the nature of the phenomenon does not make it easily amenable to experimental study. For example, it is difficult to reconcile flashbulb memory mechanisms with normal memory mechanisms (Cohen et al., 1988; McCloskey et al., 1988; Schmidt & Bohannon, 1988) and other memory mechanisms that suggest that more central elements of arousing events are better remembered. In addition the flashbulb memory theory is routed in anecdotal reports of eyewitness or other real-world testimony. As pointed

out in the introduction of this thesis, such studies are fraught with interpretive difficulties.

To summarize, the available evidence indicates that attention may interact with memory in two main ways. First, by narrowing the focus of attention (which may result in improved memory for the central rather than the peripheral elements of to-be-remembered stimuli), second, by broadening the focus of attention so that, under certain circumstances, all encountered information will be well remembered. Therefore, research indicates that emotion affects and directs attention in certain ways so that aspects of a stimulus will be remembered differentially if the stimulus is emotional in nature compared to if it is neutral in nature.

One of the difficulties of the experimental findings described in this thesis is that the effects of emotion on memory are associated with attention. Attention must be paid to an emotional stimulus before it initiates an emotional response. However, some of the experimental chapters described here, alongside other research seem to indicate that emotion affects memory differently to the way attention affects memory.

In Chapter 3, for example, it is possible to suggest that the effect of the drug manipulation on memory was via the drug's subtle effects on attentional processes. However, participants' subjective reactions to the stimuli presented did not differ between groups. In the second instance, current human research suggests that the expected effects of selective noradrenergic inhibition on attentional processes should lead, if anything, to the opposite pattern in memory performance. Coull and colleagues (1995) investigated the effects of reducing noradrenergic function on

attentional processes in man. They assessed attention in two tasks. The first of these, an 'attentional search' task required participants to respond as quickly as possible to the target words ('left' and 'right') by pressing either a left hand or a right hand computer key. These words could appear on the left- hand side or the right hand side of a screen and could be accompanied by a distracter word on the other side of the screen to the target word. Words could appear close to a centre point on the computer screen or at peripheral positions on the screen. Words could also appear in an 'incongruent' position on the screen (the word 'left' appearing on the right hand side of the screen). The task required participants to respond quickly and correctly to target words that had to be 'searched for' on the screen. The second task was an assessment of attentional focus. The same target words ('left' and 'right') were presented for an appropriate response (right hand key for the word 'right' left- hand key for the word 'left'). However, in the attentional focus task, the target words appeared in the centre of the screen and were accompanied by distracter words appearing either proximally or distally on either side of the target word. This second task was an assessment of how quickly and accurately participants would respond to the centre target words with distracters appearing peripherally. It was assessment of the degree to which participants could maintain attentional focus on the central target stimuli.

Participants who received the mixed $\alpha 1/\alpha 2$-agonist clonidine, which reduces noradrenaline release from the presynaptic terminals, showed no difference from controls on the attentional search task. However, in the 'focus' task, unlike controls, who gradually responded faster to the central target words when distracters were far

away, clonidine treated participants failed to show an improvement. This finding for the 'distal' stimuli and not the proximal stimuli was interpreted by Coull et al., (1995) as a broadening of the focus of attention in that the clonidine participants were more distracted by extraneous stimuli. Clonidine, according to Coull et al., "broadened the focus of attention to a deleterious effect" (p227). If drugs that *reduce* noradrenergic function broaden the focus of attention, it is reasonable to hypothesize that drugs that selectively *increase* levels of noradrenaline will narrow the focus of attention (i.e. decrease attentional search and increase attentional focus). If this is the case, it is reasonable to propose that the effects of reboxetine on subject's attentional behavior was to increase their focus on the to-be –remembered stimuli. Therefore, one would predict the opposite pattern in memory performance to that observed (an increase in memory performance) for the reboxetine groups relative to placebo. The memory impairment seen in the study reported in Chapter 3 is unlikely to have been due to the effects of the pharmacological manipulation on attention. This interpretation is based on the evidence from the recorded subjective responses to the slide stimuli. It is also based on the findings of other studies, which reduce levels of noradrenaline in the brain, which have been described above (e.g. Coull et al., 1995).

In addition, attempts were made to control for possible differences in the attention paid to stimuli that were emotional in nature compared to stimuli that were neutral in nature in Chapter 6. This was achieved by limiting the amount of time participants had to fixate on all IAPS images be they neutral or emotional to 80 milliseconds. Previous research has established that such brief presentations are effective in limiting eye fixations (Sergent, 1982). Furthermore, studies of memory

for emotional material have adopted this brief presentation approach to try to control for the effects of attention on performance (Christianson et al., 1991; Christianson & Fallman, 1990). While limiting the attention participants paid to stimuli, the results of Chapter 6 indicate that errors made in the recognition assessment to images that were classified as high arousal were approximately double those made to images that were classified as low arousal in the control group (and at chance levels – see Appendix 10). This indicates that, when controlling for attention, healthy adults make more recognition errors to highly arousing images than to low arousal images. This indicates that the effects of emotion on memory performance cannot easily be explained in terms of attentional bias for emotional material.

7.2.3. Theme 3: What has this thesis contributed to current knowledge concerning the structures and mechanisms that may underpin emotional memory functioning in man?

The picture emerging from the research with animals has been summarized in a model of the interactions of hormones and neurotransmitter systems in regulating memory storage for emotional events (see McGaugh 2000 and 1993 for this model). The model suggests that following an emotional stimulus, the body releases stress hormones such as adrenaline (from the adrenal medulla), which activate a central noradrenergic system that projects to the amygdala. The amygdala is activated and influences the storage of the specifically emotional memories in brain regions involved in memory. According to such models, the

amygdala, activated by a central noradrenergic system, has a time-limited role in the storage of arousal- mediated memory.

This thesis has assessed the role played by both self-rated and physiological arousal in response to stimuli and the degree to which other mechanisms other than arousal may affect memory (i.e. distinctiveness of the to-be–remembered stimulus). However, the research with animals reviewed in Chapter 1 has emphasized the need to isolate the specific effects of arousal on memory in humans also. The thesis has accordingly assessed two main issues central to the biological processes believed to be involved in emotional memory performance and related them to emotional memory functioning in man, namely the role played by a central noradrenergic system in the storage of arousal mediated memory and the role played by the human amygdala in the left and the right hemisphere in memory for emotional material.

7.2.3.1. A role for the central noradrenergic system in memory for emotional material in man?

It was predicted that selective noradrenaline re-uptake inhibition would enhance memory for emotional material, considering the wealth of animal and growing body of human literature implicating this system in the modulation of arousal mediated memory. Blockade of the beta-adrenergic system in humans results in decreased recall and recognition memory performance, relative to placebo for elements of a series of slides accompanied by an emotional narrative. Stimulation of this system with yohimbine has resulted in increased recall and recognition performance relative to placebo for the same stimulus materials.

We found a dose dependent effect on recall and recognition scores *opposite* to the predicted direction (placebo> 4mg>8mg reboxetine) and no significant differences between groups in self-rated stress and arousal scores or self-rated emotional reactions to the stimuli. It would appear that this result raises serious questions for theories, which propose a particular role played by a central noradrenergic system in emotional memory performance in man. However, three main alternative explanations for our results are possible.

In the first instance, the observed differences in memory scores for both recall and recognition between placebo and drug manipulation may have been due to an indirect pharmacological effect of the drug resulting in sedative effects on memory. However, the drug manipulation did not impair subjective arousal at the time 'encoding' of the 'to-be-remembered' stimuli took place.

In the second instance it is possible that the dose dependent increase in memory predicted was inappropriate. McGaugh and colleagues (McGaugh, 1993) have presented extensive evidence that memory is modulated by a variety of hormones and drugs in a dose dependent way, with low doses typically enhancing retention and high doses typically impairing retention. It is possible that both the 4mg dose of reboxetine and the 8mg dose represented relatively high doses and thus impaired memory dose dependently. This should not lead to the general conclusion that increasing circulating noradrenaline impairs memory. In the light of this second alternative explanation, a wider range of doses may reveal memory-enhancing effects of low doses.

In the third instance, other neurotransmitter systems such as the dopaminergic system and 5-HT systems may be implicated in memory modulation. O'Carroll and colleagues (1999b) tested emotional memory performance in participants whose adrenergic system was manipulated using beta-blockade and stimulation. Beta blockade was employed using metoprolol (a β1-receptor antagonist). Stimulation of the noradrenergic system was achieved with yohimbine (which stimulates noradrenergic activity via blockade of the α2-2 adrenergic autoreceptor. They found that blockade of the adrenergic system impaired memory for emotional material relative to placebo while stimulation of the same system increased memory for emotional material relative to placebo. However, as well as stimulating the noradrenergic system, yohimbine affects other neurotransmitter systems such as the dopaminergic system and the 5-HT system (Den Boer et al., 1993). It is possible that the emotional memory effect observed in the O'Carroll et al., study (1999b) following yohimbine was a result of the effect of yohimbine on these other neurotransmitter systems. The yohimbine effect on emotional memory may be due to the drug's effects on dopamine or 5-HT independently of its effect on noradrenaline. Alternatively, the memory enhancing effect may be due to the interaction of the drug's effects on the three systems (noradrenaline, dopamine, 5-HT). These suggestions provide avenues for further research. The study reported in Chapter 5 could be interpreted more easily in the light of further research of the effects on emotional memory of agonists and antagonists of dopamine and 5-HT. It seems clear that the memory impairment seen in the current study with participants receiving reboxetine cannot be attributed to between-subject differences in

physiological responses to stimuli or subjective reactions to stimuli (because there were none). It also seems unlikely that the differences between participants were due to the effect the drug had on attention.

7.2.3.2. The role of the human amygdala in emotional memory functioning

The third theme investigated in this thesis relates to the neuropsychological and neurobiological elements of emotional memory. Interpreted in the light of the current literature, the two studies reported in Chapters 5 and 6 are clearly complementary. Work that has been influenced by animal research suggests that the noradrenergic system (manipulated in Chapter 5), and the human amygdala (studied in Chapter 6) are both intimately involved in human emotional memory performance.

It has been suggested that the amygdala has a time-limited role in influencing the storage of memories in other brain regions that elicit physiological (e.g. hormonal) responses (McGaugh et al., 1993). The notion that the amygdala is involved in certain arousal-related aspects of an emotional experience is becoming increasingly established. With animal participants Cahill and McGaugh (1990) have demonstrated that amygdalar lesions do not block acquisition of simple appetitively motivated learning tasks (like learning to locate a water reward in a 'Y' maze). However, lesions to the amygdala did significantly impair retention of aversive learning. For example, if an animal received a foot shock on training day three when

performing the appetitively motivated 'Y' maze water- search task learned over the previous 2 days, normal animals displayed a dramatic and expected increase in latencies to drink on day 4. However, amygdala lesioned animals did not demonstrate this dramatic increase in latency. They were significantly quicker to drink on day four after the foot shock than the control animals who had received a similar foot shock on day three (Cahill and McGaugh, 1990). Even more compelling perhaps is the observation that noradrenaline is released in the amygdala following foot shock stimulation (Galvez et al., 1996) and that the amount of noradrenaline released varies directly with the intensity of stimulation (Quirarte et al., 1998). Taken together, these two findings implicate the neurotransmitter noradrenaline, intense arousal and the amygdala, together, in influencing emotional memory.

It appears that the healthy human amygdala is similarly associated with 'high arousal' learning scenarios. It has been demonstrated that the human amygdala activates in response to high arousal visual images regardless of their pleasantness (Hamann et al., 1999). In addition, damage to the amygdala impairs memory for images that are highly arousing regardless of their valence (Phelps et al., 1998). The study reported in Chapter 6 has demonstrated that the perception of a stimulus in terms of self-rated arousal and valence is the same in controls and participants with amygdala damage when the rating occurs at encoding. What differs is the memory performance of participants with right amygdala damage for stimuli rated previously. The study reported in Chapter 6 also provides support for the interpretation that in the undamaged brain, the amygdala, in the right hemisphere, may underpin the processes by which subjective emotional responses to stimuli are

translated into enhanced declarative memory for those stimuli. After damage to the right amygdala, subjective emotional responses to stimuli are not significantly different from controls but memories for those stimuli are disrupted. However, damage to the left amygdala coincides with normal ratings of arousal to right amygdala damage, but without the associated memory impairment for those stimuli. This provides tentative support for the interpretation that right amygdala, rather than the left amygdala translates subjective responses into enhanced memory when emotionally arousing material is presented.

Another avenue of investigation of the role played by the amygdala in emotional learning in animals may help the interpretation of human studies that have found an emotional memory impairment following amygdala damage (e.g. Cahill et al., 1995). This body of evidence comes from studies of instrumental conditioning following amygdala lesions. In a recent review of current work, Killcross (2000) has outlined subtle differences between amygdala lesioned animals and controls in their ability to form and use mental representations of rewarding outcomes. For example, Hatfield et al., (1996) demonstrated that amygdala damage is associated with a failure to show elimination of responses leading to a food reward upon which the animal has been previously satiated (in a paradigm known as 'sensory-specific satiety'). Typically, in normal control animals, pre-feeding on a certain reward (e.g. food pellets) will tend to eliminate responses resulting in the delivery of food pellets. However, responses resulting in the delivery of other rewards (e.g. sucrose) during a test session will be preserved. The failure in response- reward learning following amygdala lesion is not due to the fact that animals cannot discriminate between

pressing one lever (for food pellets) and another (for sucrose). Amygdala lesioned animals can learn simple chains of instrumental responses. It appears that the failure of animals with amygdala damage to learn about the value of reward is due to an inability to distinguish between different rewards. For example, using a 'differential outcomes' paradigm, Killcross and colleagues (Killcross, 2000) demonstrated that rats learned to press one lever in the presence of one auditory tone and another in the presence of a different auditory stimulus. In other words, 'lever 1' would be pressed in the presence of a tone and 'lever 2' would be pressed in the presence of an auditory click. If a rat pressed the correct lever in the presence of a given tone, the animal was rewarded, if the incorrect lever was pressed during a given tone, the animal was not rewarded. If correctly pressing one lever produced sucrose and correctly pressing another lever produced food pellets, the discrimination was learned even more easily (differential outcomes effect). However, while rats with amygdala damage learned to discriminate between pressing one lever in the presence of tone and a different lever in the presence of a click, they did not show the differential outcomes effect. In other words, they did not benefit from having two different rewards. This finding indicates amygdala damage in rats is associated with a failure to discriminate between different rewards in terms of behaviors designed to gain those rewards.

Further evidence indicates that amygdala lesioned animals will demonstrate the usual elevation of lever-press responding during a signal for food (transfer of control design) but the responding is not selective to the reward being earned. In contrast, sham animals show this selectivity and will press the lever that predicts the

same reward as the signal. This finding is interpreted as evidence to indicate a failure to represent properly the sensory aspects of the reward in relation to the reward's effect upon motivation (Killcross, 2000). In other words, the increase in lever pressing in the amygdala lesioned animals when a given tone is presented represents a generalized increase in responding. The animals do not learn that the presence of the tone predicts the same reward as pressing a given lever.

The research on associative learning in animals following amygdala damage indicates that a) amygdala damage is associated with a failure to learn the value of one reward compared to another. That b) this failure is due to an inability to distinguish between different rewards. In addition, c) that amygdala damage results in a failure to form correct representations of the sensory properties of a reward.

How can these findings be related to the current finding reported in Chapter 6? It would appear that damage to the right amygdala in humans is associated with emotional memory impairment for visual images and words. This damage occurs alongside normal responses in terms of valence ratings and idiosyncratic arousal responses. The animal research indicates that the amygdala plays a role in the formation of representations (that may constitute later memories perhaps) about emotionally significant events (rewards in the associative learning literature). Amygdala damage appears to result in a failure to distinguish between different emotionally significant events and this finding is particularly interesting for studies of human amygdala function. It is possible, for example, that the emotional memory impairment demonstrated in the patient SE, with right amygdala damage, may represent a failure to learn the subtle differences between emotional and neutral

images. SE failed to show the normative pattern of enhanced memory for the second, middle phase of the Cahill slide stimuli compared to the first neutral phases. For SE, all stimuli were remembered similarly. Interpreting this finding in the light of the associative learning research, it is possible to suggest that patients with right amygdala damage fail to form the appropriate mental representations of emotionally significant stimuli as being different, distinct perhaps from neutral stimuli. What is more, this failure may be linked with an atypical response to the stimuli (in terms of the arousal rating), perhaps an inability to distinguish between emotional and neutral images in terms of how they should respond. Perhaps this failure is similar to the failure of animals with amygdala damage to be sensitive to the changes in the value of rewards and how best to attain those different rewards. The humans with amygdala damage described in Chapter 6 did, however, produce ratings of pleasantness in response to the stimuli that were similar to controls. It is possible that humans with amygdala damage learn to associate certain visual stimuli with certain subjective responses in a similar way to amygdala lesioned animals. Animals with amygdala lesions discriminate between responses based on an emotionally significant reward being present or absent. With humans who have amygdala damage, these associations between stimuli and subjective responses are tenuous and often differ from the responses of healthy adults (in terms of arousal responses specifically). Perhaps this difficulty in appropriately rating images in terms of arousal provides a clue to the difficulty experienced by humans with amygdala damage distinguishing between different *kinds* of emotions represented in images. The mechanisms underlying the emotional memory impairment in humans appear to

be linked with the side of the amygdala damage. The responses at presentation of the visual stimuli used in Chapter 6, in terms of valence ratings, did not appear to be different from the responses of controls but the patients demonstrated idiosyncratic arousal ratings (N.B. arousal ratings were not statistically significantly different between patients and controls). This, in itself, indicates that amygdala damage is associated with a difficulty in appropriately discriminating between different stimuli in terms of arousal. This difficulty is associated with a memory impairment in a right amygdala damaged patient. The amygdala, in both hemispheres, may therefore be implicated in the processes of distinguishing between stimuli in terms of their associated arousal. The right amygdala specifically may be implicated in the process of translating an emotional response to a stimulus into enhanced memory for that stimulus.

7.3. Methodological considerations relating to the current work

7.3.1. Human performance following selective brain damage: The need for cautious interpretation

The study presented in Chapter 6 of this thesis compared amygdala damaged patients with a healthy control group on a range of emotional as well as neutral memory tasks. The damage sustained to the amygdala in patients SE and DR was however, not selective. Future studies should compare patients with differentially severe amygdala damage with patients who have undergone surgery to the brain that

has not involved amygdala damage and a healthy control group that have undergone no surgical intervention. It is possible that surgical intervention itself affects affective states and that damage to the amygdala is coincidental in this response. (e.g. Luciano et al., 1993; Wang et al., 1995; Montenegro et al., 2000). Patients with selective amygdala damage are rare and patients who have undergone left temporal lobe surgery centered on the amygdala to control epilepsy may provide an important group of participants to assess the hypothesis in relation to emotional memory and the right hemisphere amygdala. It is clear that careful comparisons of neuropsychological function should be made between participants to avoid the possibility of confounding effects of non- specific emotional responses, or cognitive deficits as a result of the clinical condition and/or surgical intervention.

It is clear that the neuropsychological method of investigating the relationship between brain structure and damage on the one hand to functioning on the other should always co-exist with functional imaging activation studies of healthy brain functioning. In the case of emotional memory functioning, it is difficult to claim definitively that amygdala damage subserves emotional memory functioning in the normal brain. It is important to always bare in mind the salutary advice offered by Lezak:

"The uncertain relation between brain activity and human behaviour obligates the clinician to exercise care in observation and caution in prediction, and to take nothing for granted when applying the principles of functional localisation" (Lezak, 1995, p96)

Damage is rarely selective (both SE and DR's damage was to some extent bilateral rather than solely unilateral). This limits the conclusions made in this thesis in relation to the effects of lateralized amygdala damage on emotional memory performance.

7.3.2. Physiological indices of arousal: source dependent or incidental?

A cautionary note should also be made concerning the conclusions to be drawn from the physiological indices of arousal recorded in chapters 2, 3, 4, and 5. This note concerns the effects on memory of stimulus-elicited arousal. The mean change from baseline GSR response employed in the study reported in Chapter 2 was recorded at the time of stimulus presentation and gives an indication of physiological arousal at the time of stimulus presentation. Each subject's mean GSR response was recorded 1 second following stimulus onset until stimulus end (GSR response latency tends to vary between 1 and 4 seconds following stimulus onset – Hugdahl, 1995). Therefore, averaging responses across trials was the norm for all participants. Typically the parameters of stimulus onset, the initiation of GSR, the amplitude of the response from base level to peak and the half time recovery were all recorded for each trial for all participants and used in analysis. Therefore all accepted measurement parameters of the phasic response were used. Although obvious external variables were minimised, any that did occur during stimulus presentation were marked and contributed to the exclusion of a GSR response from later analysis.

Nevertheless, a number of other variables other than the words themselves may have been recorded and analyzed as GSR responses to words. For example, it is possible that naming colours used as filler items between words served to produce anxiety reflected in the GSR recording for some participants in the study reported in Chapter 2. It is unlikely that an explanation based on subject arousal to other cues and not the word presentation could explain the consistent pattern of higher responses to words classified as taboo and lower responses to items classified as neutral. However, there was a large standard deviation implying marked individual differences. Some participants produced very low GSR responses and other participants, high GSR responses to a word chosen to illicit high GSR responses. In addition, using change from baseline measurements of GSR represents physiological arousal at the time of stimulus presentation. To more precisely determine the degree to which stimulus elicits a response requires use of area under the curve in addition to change from mean baseline calculations (Busch & Hudson, 1996). Area under the curve calculation is a more sensitive representation of the magnitude of a response. The mean GSR represents the average value of a response (i.e. between baseline and the response peak), this does not take into account that the duration of a response may differ as result of the presentation of different stimuli. The area under the curve calculation measures the area between the deflection point of the response (i.e. the initial rise in GSR) and the point where the recovery reaches the initial baseline. A protracted response would be represented by a greater area value whereas the mean calculation for the same response would only measure the average value between baseline and peak. GSR arousal in Chapter 2 of the thesis should be understood as arousal occurring *at the time of stimulus presentation* rather than stimulus elicited

arousal. The area under the curve calculation employed in Chapter 5 represents a more accurate measurement of arousal in response to stimuli than the calculation of average GSR during stimulus presentation employed in Chapter 2. However, both these methods (i.e. area under the curve and change from mean baseline have been employed in either previous studies in the field or in current manuals relating to psychophysiological recording techniques (Biopac - Model MP30, Biopac Systems Inc., Linton Instrumentation, Norfolk).

7.3.3. Self-ratings of valence and arousal: Was the task too hard for some patients?

In Chapters 5 and 6 of this thesis, the method adopted for the collection of subjective self-ratings was the method employed by Lang and his colleagues (1999) and by a number of other researchers in the field. The use of the self-assessment manikin method of assessment in these chapters has an important advantage and an important disadvantage.

The important advantage in using the self-assessment manikin in conjunction with the International Affective Picture System corpus of images in Chapter 5 of this thesis was that the picture set generates extremely reliable emotional report data. This method of providing reliable self-ratings in response to standardized stimuli has been widely adopted and appears essential in any study of the effects of emotion on memory. The self-rating measure has been shown to covary with electromyographic measures (zygomatic/corrugator) as well as visceral ones (heart rate/skin

conductance measures). Specifically, valence ratings covary with facial responses, and arousal ratings significantly vary with GSR responses (Lang et al., 1993). Normative ratings of valence and arousal have been collected for the 700 images that make up the corpus. The normative ratings have continued over the past 10 years (Lang et al., 1999). In addition, the publication of the corpus and the normative ratings allows for easy replication of the results of this thesis.

One important disadvantage with using these standardized methods of collecting self-rated emotional reactions in response to images becomes apparent in Chapter 6. Some patient groups find certain facial expressions difficult to recognize (Calder et al., 1996). In the case of patients with amygdala damage, the facial emotion recognition deficit appears to be specific to facial expressions of fear. It is possible to criticize the study reported in Chapter 6 on the basis that the method employed to assess 'valence' was inappropriate. This is because the valence report measure of the self-assessment manikin depicts a series of manikins representing 'pleasantness' in terms of gradually changing facial expressions (upturned mouth = pleasant – down turned mouth = unpleasant). It is possible to argue that the results of the valence ratings collected from the patients with amygdala damage are unreliable and may represent a misunderstanding of the requirements of the rating exercise in terms of valence.

Although amygdala damage is reliably associated with deficits in the recognition of facial fear expressions, there is no evidence to suggest a similarly severe deficit in terms of the recognition of the expressions displayed on the self-assessment manikin (the 'fear' facial expression is also not represented on the self

assessment manikin). Furthermore, the results of the study reported in Chapter 6 suggest that ratings of valence in response to presented images were remarkably similar between both the patients and the healthy adults. Ratings of arousal, which are not represented in terms of facial expressions at all on the manikin were markedly less similar between patients and healthy controls. In itself this would indicate that participants, both patients and controls were using the self-assessment manikin to report valence related feelings in an appropriate way. Furthermore, it was an added requirement in all studies reported in this thesis which used the IAPS range and the self assessment manikin that participants should also provide a written description of the stimulus presented to them. It was made clear to participants that they should avoid mentioning emotion related words in descriptions and confine their responses to descriptions of the content of the image. However, one of the patients (SE) reported in chapter six tended to provide an emotion related commentary when completing the written description. This commentary often supported the rating of valence he made in response to the image.

Taken together, this evidence would suggest that patients with amygdala damage rated the valence of images presented to them in a similar way to controls. Other evidence suggests these patients understood how to use the scales appropriately. Therefore the advantages gained by using a standardized set of images and a reliable rating measure of those images outweighed any disadvantages in terms of task difficulty.

7.3.4. Normative studies of arousal and valence ratings for both images and sounds: Studies need more stimuli.

Relating to the previous section, one of the shortcomings of the research reported in Chapters 5, and 6 of this thesis was that a larger number of less pleasant stimuli would have been preferable. More stimuli would have enabled a more subtle demonstration of the effects of emotion category on emotional responses and on memory. In Chapter 5, a series of 5 targets and five distracters (n=10) were drawn for each of five categories (total n = 50). Using this number of images produced significant between category memory effects and significant between category physiological responses. However, the single patient work (Chapter 6) would have benefited greatly from a larger number of stimuli. The reason why more stimuli were not drawn from the IAPS range was twofold.

7.3.4.1. Reason 1. Ethical considerations

In the first instance ethical considerations meant that the more extreme images in the IAPS range (in terms of both arousal and valence) could not be used due to the very real possibility of eliciting distress on the part of participants (especially the older participants participating in the study reported in Chapter 6). These ethical considerations are considered a fundamental problem in any study employing human participants and serious consideration should be paid to avoiding unnecessary distress on their part. However, the need to avoid distress should be

balanced with the need to select stimuli that are sufficiently arousing in nature to be able to elicit both subjective and physiological changes in arousal levels in order to better understand the often complex relationship between physiological arousal and subjective arousal at encoding and subsequent memory performance. Emotional memory in man cannot be studied without a reliable and meaningful means of eliciting emotion.

7.3.4.2. Reason 2. Stimulus complexity

The second reason why more stimuli were not employed in Chapter 5 of this thesis was that images had to be selected in order that they may be combined with sounds; many of the images did not lend themselves easily to being combined with sounds and had to be disregarded. The size of the Lang et al., (1999) corpus is at present around 700 images. As the corpus increases in size, problems of stimulus numbers in studies such as these should diminish. As an addendum, it should be noted that the number of images employed in both Chapters 5 and 6 of this thesis were similar to the number employed by many of the published studies outlined in the current IAPS manual (Lang et al., 1999).

7.3.5. Time to update the Heuer & Reisberg stimuli?

The stimuli employed in Chapters 4, 5 and 6 of this thesis included as series of slides that depicted a story. The middle phase of this slide story presentation includes relatively negative emotionally arousing slides depicting surgery for injuries sustained in a car accident. The stimulus set was formulated by Heuer & Reisberg (1990) but have been extensively used (and changed slightly) in psychopharmacological studies of emotional memory (Cahill et al., 1994; 1995; van Stegeren., 1998; O'Carroll et al., 1999a, b). The stimuli were employed in this thesis on memory for emotional material because the set has been extensively used in previous published studies and produces a consistently reliable increase in memory performance for the middle, emotive phase of the story across western cultures (USA, Germany, Denmark, Scotland etc.). In addition, the series has also produced reliable increases in physiological responses and self-rated response of emotional arousal during the second emotive phase of the story across cultures (Cahill et al., 1994; van Stegeren et al., 1998). What is more, the use of this series allowed direct comparison between the study reported in Chapter 6 and other psychopharmacological studies employing the same series.

In the aforementioned chapters of this thesis and in other published studies (O'Carroll et al., 1999a/b), the emotional elements of the second phase have failed to induce a measurable physiological response. However, participants still produced an increase in memory performance for the middle phase of the story. The lack of physiological arousal in response to the stimuli may be partly because the stimuli are relatively mild and dated.

Regardless of these possibilities, the set have been used most notably to distinguish between memory for neutral as opposed to emotional material following beta blockade (Cahill et al., 1994). This seminal finding used the same series of slides as employed in the current thesis and found that beta blockade impaired memory for the slides accompanied by an emotional narrative but not the same slides accompanied by a neutral narrative. This finding in itself indicates that in spite of the shortcomings inherent in the stimuli, they reliably elucidate the role played by different drugs in memory for emotional material.

It is suggested here that future attempts to improve the stimuli should concentrate on the following areas. (a) to update the images portrayed (b) equate the three phases of the slide series in terms of slide number in each phase (at present there are 4 slides in the first two phases and three slides in the third phase meaning that scores must always be expressed as 'percent recognition/recall correct' scores). (c) Operationally define central and peripheral details in each slide and match both central and peripheral details. Defining detail may help research to gauge to the effects of arousal on attention. Central detail should be defined as 'detail central to the gist of the story' and peripheral detail should be defined as 'detail peripheral to the story'. What might be more useful is to match more subtle elements in each slide so that an assessment can be made of exactly what participants do and do not remember. Burke et al., (1991) attempted this. The study divided to-be-remembered events into those that were central elements and those that were detail elements. Half of the questions relating to central elements could probe for gist knowledge (i.e. plot), half of the questions could relate to basic levels information (i.e. is the mother

locking the house door or walking away etc.). On the other hand, detail could itself be divided into detail related to the central characters as opposed to detail associated with the background. An interesting finding of the Burke et al., study using this method was the finding that emotion led to increased memory for central details. It is important to ensure however that studies that employ complex stimuli do not become too difficult/time consuming to interpret or idiosyncratic to view. What is evident is that some form of consensus should be reached and adhered to concerning how central and peripheral details are defined across studies of human emotional memory. This should allow consistent comparisons between studies.

7.4. Summary and concluding remarks

This thesis has contributed to our understanding of the way emotional arousal modulates human memory performance. Attempts have been made to design studies that address questions relating to human emotional memory performance in a multidisciplinary way. The studies reported in this thesis have addressed a variety of questions raised in emotional memory research from different research perspectives. The reason for the multidisciplinary approach employed in this thesis is that, increasingly, the field of human emotional memory functioning is based on the principles and findings of neurobiological research with animals. Work attempting to elucidate the processes underlying human emotional memory functioning should approach questions relating to memory from psychological, physiological and

neurobiological perspectives. Each of these disciplines allows the researcher to understand memory function at different levels within the organism.

This thesis has attempted to formulate answers to questions that have been raised by current research in neuropsychology, physiology and neurobiology on the topic of human emotional memory functioning. The questions addressed include: does the way in which we are aroused affect what we remember? (Chapter 2, 3, 4 and 5), what is it about an emotional stimulus that ensures it a place in memory? (Chapter 5), what happens to these memories as time passes? (Chapter 2), at a neurobiological level, what system or systems may be involved in processes specific to emotional memory formation both in terms of chemical functions (Chapter 3) and brain structures (Chapter 6)?

A number of answers have been outlined to these questions. To answer the first question, 'does it matter how we are aroused'; it would appear that, in the laboratory, the answer is yes. Subjective rather than physiological arousal is more predictive of declarative memory for visual images and words that vary in emotive value (Chapters 2, 3, and 4). Moreover, it would appear that the interaction between the valence and arousal values of the to-be-remembered stimuli interact to predict memory. Low valence and high arousal images will be remembered better than categories based on other combinations of valence and arousal.

The second question related to the characteristics of a stimulus that determines a privileged place for it in memory. It was found that aspects other than emotion play a role in emotional memory formation. For example, the distinctiveness of a stimulus will determine memory strength for that stimulus.

However, low valence, high arousal *incongruent* stimuli are not remembered better than low valence high arousal *congruent* stimuli. This suggests that the memory improvement seen for low valence high arousal stimuli is evident regardless of the degree to which a stimulus is 'incongruent' or 'distinctive' (Chapter 5).

The third question relates to how memories for emotional material *change* as time passes. The largely accepted finding in the field of experimental psychology is that memory for emotional material 'grows' or 'incubates' as time passes, it is not just consolidated. By comparison, memory for neutral material 'decays' as time passes according to current wisdom. The study reported in Chapter 2 of this thesis failed to find any evidence for incubation in memory for emotional material. Classifications of 'emotional' and 'neutral' were varied in terms of subjective responses, pre-classifications and physiological responses, and all stimuli were matched for frequency of occurrence. When applying these rigid controls, emotional material was remembered consistently better than neutral material and decayed over the passage of time in a similar pattern to neutral material. Based on the current findings it is suggested that caution should be exercised when concluding that memory for emotional material is robust and becomes *more* robust over time.

At a neurobiological level, we asked what system or systems may be involved in processes specific to emotional memory formation both in terms of neurotransmitter functions (Chapter 3) and brain structures (Chapter 6). The current human and animal literature on the memory modulating role of stress hormones led us to believe that drugs that increase circulating central noradrenaline levels in a highly selective way would also improve memory for emotional material. We found

the opposite, that such drugs impaired memory in a dose dependent manner. This finding has led to a number of testable hypotheses relating to the subtle effects of different amounts of noradrenaline in memory modulation and the effects of different neurotransmitters in interaction with noradrenaline in memory modulation. Finally, in terms of brain structures involved in emotional memory functioning, it has been demonstrated in this thesis that the amygdala in the right hemisphere may be particularly implicated in emotional memory functioning in man. Neuropsychological research in this field has largely studied participants with bilateral damage to the amygdala and has found an emotional memory impairment in these patients. It is suggested here that the damage to the right hemisphere in these cases may be largely responsible for the emotional memory impairment observed.

To conclude, Chapter 1 of this thesis opened with William James' insightful observation that 'selection is the very keel on which our mental ship is built'. Selectivity has special relevance for research associated with the interface of arousal and biology on the one hand and cognition and memory on the other. It would appear self evident that the study of memory in humans *must* include, at its base, a consideration of why certain aspects of the external world are remembered and other aspects are forgotten. Human memory occurs as a result of our interaction with the external world and is fundamentally manipulated by reactions to that external world. It is suggested that studying the selectivity of human memory for aspects of the external world that elicit an emotional response allows us to understand the intimate relationship between cognitive and physiological functioning. Understanding memory functioning in humans cannot be fully achieved without understanding how

the two systems interact. The experimental chapters of this theses have demonstrated that research on human memory functioning in psychology can be enriched by the wealth of neurobiological literature in this area. The present work has attempted to extend this field to the study of human emotional memory functioning by elucidating the degree to which response characteristics, stimulus characteristics, pharmacological and neurological characteristics affect memory for emotional material in man.

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Appendices

Appendix 1: taboo and neutral words matched for frequency of occurrence in the English language.

Key:

n: noun
v: verb
aj: adjective
n/v: refers to an uncertain categorization as to whether a word was a singular common noun or base form of a verb

Word	word class	frequency
Shit	**n/v**	**161**
Palm	**n/v**	**158**
Rape	**n/v**	**295**
Rule	**n/v**	**295**
Penis	**n**	**519**
Jelly	**n**	**517**
Whore	**n/v**	**24**
Pleat	**n/v**	**24**
Asshole	**n**	**46**
Bivouac	**n**	**46**
Fuck	**n/v**	**171**
Stamp	**n/v**	**174**
Fart	**n/v**	**10**
Band	**n/v**	**10**
Nipple	**aj/n**	**135**
Rotary	**aj/n**	**135**
Murder	**n/v**	**212**
Filter	**n/v**	**210**
Masturbate	**v**	**8**
Intercept	**v**	**8**
Bastard	**n**	**55**
Enigma	**n**	**55**
Cocaine	**n/v**	**138**
Harvest	**n/v**	**137**
Horny	**aj**	**86**
Tinted	**aj**	**86**

Molest	**v**	**15**
Cobble	**v**	**15**
Incest	**n**	**305**
Walnut	**n**	**305**
Orgasm	**n**	**178**
Layman	**n**	**178**
Tits	**n**	**244**
Apes	**n**	**245**
Homosexual	**aj/n**	**48**
Chattering	**aj/n**	**48**
Amputate	**v**	**13**
Discerns	**v**	**13**
Herpes	**n**	**102**
Kennel	**n**	**102**

Appendix 2: The narrative accompanying the 11 slide story presentation

First phase:

"Slide 1. A mother and son are leaving home in the morning.

Slide 2. She is taking him to visit his father's workplace.

Slide 3. The father is a chief laboratory technician in a nearby hospital.

Slide 4. They check before crossing a busy road."

Second phase:

"Slide 5. While crossing the road, the boy is struck by a runaway car, which critically injures him.

Slide 6. At the hospital, the staff prepare the emergency room to which the boy is rushed.

Slide 7. All morning long, surgeons struggle to save the boys life.

Slide 8. Specialized surgeons were able to successfully re-attach the boys severed feet."

Third phase:

"Slide 9. After the surgery, while the father stayed with the boy, the mother left to phone her other child's pre-school.

Slide 10. Feeling distraught, she phones the pre-school to tell them she will soon pick up her child.

Slide 11. Heading to pick up her child, she hails a taxi at the number 9 bus stop.

End of tape"

Appendix 3: Thematic arousal Study: Recognition memory test.

There will be 5-9 multiple choice questions per slide and I will begin with slide 1 and move progressively on to the subsequent slides. I will tell you exactly when the questions start to refer to the next slide. You will always know to which slide (out of 11) a question refers. Sometimes a question will tell you were right or wrong on a previous question, if you were right, great, if you were wrong, just keep going on.

Slide 1:1
Who is pictured in slide 1?
a) a mother and her son
b) a father and his son
c) a mother and father
d) no one is pictured

Slide 1:2
What are the mother and son doing?
a) eating at a table
b) leaving home
c) walking
d) riding in a car

Slide 1:3
Where are the mother and son standing?
a) in front of a school
b) in front of their home
c) at a bus stop
d) next to their car

Slide 1:4
What is the mother doing?
a) locking the house door
b) tying her son's shoe
c) getting into her car
d) standing in a doorway

Slide 1:5
What is the colour of the house door?
a) green
b) black
c) red
d) blue

Slide 1:6
What is visible in the foreground of the picture?
a) lawn
b) trees
c) steps
d) driveway

Slide 1:7
What is the boy carrying?
a) a soccer ball

b) his lunch
c) a backpack
d) a teddybear

Slide 1:8
What time of day is it?
a) morning
b) afternoon
c) evening
d) was not mentioned

Now the second the slide
Slide 2:1
Who is pictured in slide 2?
a) mother
b) son
c) mother and son
d) mother and son and one other person in background

Slide 2:2
What are they doing?
a) standing
b) sitting
c) walking
d) running

Slide 2:3
Where are they going?
a) to school
b) shopping
c) father's workplace
d) mother's workplace

Slide 2:4
What is their position relative to each other?
a) walking arm in arm
b) walking hand in hand
c) he is holding her jacket
d) there is no contact between them

Slide 2:5
What is their position relative to each other from the viewers perspective?
a) he is on the left
b) he is on the right
c) he is in front of her
d) he is behind her

Slide 2:6
You were told that they
a) had long planned to do this
b) did it on the spur of the moment
c) did it after receiving a phone call

d) no such information was given

Slide 2:7
Their facial expression is
a) neutral
b) sad
c) happy
d) excited

Slide 2:8
How much of the child can you see?
a) full body
b) shoulder up
c) waist up
d) knees up

Slide 2:9
Which direction are they walking relative to the viewer?
a) towards the viewer
b) away from the viewer
c) to the left
d) to the right

Now the third slide
Slide 3:1
Who or what is pictured next?
a) the mother and son
b) the father
c) all three
d) a hospital

Slide 3:2
You were told that the father's occupation is
a) a school teacher
b) a surgeon
c) a laboratory technician
d) hospital custodian

Slide 3:3
What is the father doing in this slide?
a) working at a lab bench
b) looking into a microscope
c) sweeping the floor
d) posing, looking directly at the camera

Slide 3:4
Relative to the viewer, he faces

a) left
b) right
c) directly towards the viewer
d) away from the viewer

Slide 3:5
Pictured in the background is
a) a microscope
b) a door
c) a window
d) some chemicals

Slide 3:6
The father has
a) glasses
b) beard
c) both
d) neither

Now the fourth slide
Slide 4:1
Who is pictured in the next slide?
a) mother
b) mother and son
c) father and son
d) no one

Slide 4:2
What are the mother and son doing?
a) getting into a car
b) getting into a bus
c) waiting at a stop light
d) checking before crossing the street

Slide 4:3
Which direction are they looking from the viewers perspective?
a) both left
b) both right
c) mother left and son straight ahead
d) mother right and son straight ahead

Slide 4:4
What is in the background?
a) trees
b) a house
c) a parked car
d) a bicycle

Slide 4:5
The boy stands where relative to the mother from the viewers perspective?

a) on the right
b) on the left
c) in front of her
d) behind her

Slide 4:6
They are standing next to a
a) street sign
b) parked car
c) stop light
d) telephone pole

Now the fifth slide
Slide 5:1
What is pictured next?
a) an intersection
b) an ambulance
c) a car off the road
d) a tow truck with A car

Slide 5:2
What happened in this slide?
a) The boy saw a bad accident happen
b) the boy was hit by a run away car
c) the boy saw some wrecked cars in a junkyard
d) they walked past the scene of a minor accident

Slide 5:3
You were told that the boy
a) was knocked unconscious
b) was critically injured
c) was trapped under the car
d) was mildly hurt

Slide 5:4
Who was visible in the slide?
a) mother
b) boy
c) some unnamed people
d) no one

Slide 5:5
The colour of the car pictured was
a) green
b) grey
c) blue
d) brown

Slide 5:6
The car was facing
a) towards the viewer to the right
b) away from the viewer to the right
c) towards the viewer to the left
d) away from the viewer to the left

Slide 5:7
In addition to the car you could also see
a) an ambulance
b) a tow truck
c) other cars driving by
d) a parked car in the background

Slide 5:8
What was located in the foreground of the picture?
a) a bicycle
b) a fire hydrant
c) some broken glass
d) a water-sewer cover

Slide 5:9
The colour of the hydrant was
a) white
b) yellow
c) red
d) two-toned

Now the sixth slide
Slide 6:1
What is pictured next?
a) a tow truck
b) an ambulance
c) a busy street
d) a hospital

Slide 6:2
You were told that the hospital staff
a) prepared the emergency room for the boy
b) are working on victims of a bus crash
c) are preparing for a disaster drill
d) it was not mentioned

Slide 6:3
What is the colour of the hospital?
a) green
b) pale blue
c) grey

d) light brown

Slide 6:4
What is the name of the hospital?
a) Bannam County Hospital
b) County Hospital
c) Victory Memorial Hospital
d) St. Vincent's Hospital

Slide 6:5
What kind of vehicles are pictured in front of the hospital
a) cars
b) ambulances
c) supply trucks
d) none are pictured

Slide 6:6
How much of the hospital is visable
a) ground floor only
b) ground floor and the second floor
c) many floors
d) many floors and the roof

Now the seventh slide
Slide 7:1
What is pictured next?
a) mother
b) surgeons
c) father
d) nurses

Slide 7:2
Where are the surgeons pictured?
a) in an operating room
b) scrubbing for surgery
c) in a hallway
d) by a door

Slide 7:3
The surgeons were
a) talking with the boy's parents
b) practising drill procedures
c) working on the boy
d) it was not mentioned

Slide 7:4
What people were visible
a) boy and surgeons

b) several surgeons in the background
c) several surgeons in the background and one in the foreground
d) two surgeons in the foreground

Slide 7:5
The surgeon in the foreground is wearing
a) a surgical gown only
b) a surgical gown and surgical hat
c) glasses and surgical gown
d) all of these

Slide 7:6
What is the expression on his face?
a) sad
b) happy
c) neutral
d) shocked

Slide 7:7
You were told that the surgeons worked
a) all morning long
b) all day long
c) all afternoon long
d) it was not mentioned

Now the eighth slide
Slide 8:1
What is pictured next?
a) doctors talking to nurses
b) father and mother
c) the boy after surgery
d) the father and the boy

Slide 8:2
What had been done to the boy?
a) skin grafts were put on his legs
b) his feet were re-attached
c) his broken legs were in cast
d) it was not mentioned

Slide 8:3
What part of the boy is shown?
a) head only
b) whole body
c) legs only
d) torso only

Slide 8:4
Where were scars visible on the body?
a) on feet
b) near the ankles
c) on the knees
d) there were no scars visible

Slide 8:5
What else is pictured besides the boy
a) a surgical tool
b) an iv drug line
c) pillow
d) nothing

Slide 8:6
What is the position of the boy?
a) lying on his stomach
b) lying on his back
c) lying on his side
d) sitting

Now the ninth slide
Slide 9:1
Who leaves the hospital?
a) the father
b) the mother
c) the mother and son
d) the mother and father

Slide 9:2
Why does the mother leave?
a) to call her parents
b) is late for her job
c) to call her other child's school
d) has an appointment

Slide 9:3
What is she holding in her hand?
a) her purse
b) her keys
c) a soccer ball
d) nothing

Slide 9:4
What is she walking near?
a) a police station
b) a train station
c) a library
d) a sky scraper

Slide 9:5
What is she walking towards
a) a street light
b) a taxi stand
c) a street vendor
d) a telephone booth

Slide 9:6
Which way is she facing
a) towards viewer
b) away from viewer
c) walking to left
d) walking to right

Slide 9:7
The mother's purse is where?
a) in her hand
b) over her shoulder
c) she is not carrying a purse

Slide 9:8
In the middle of the picture is a:
a) tall tree
b) stop sign
c) tall pole
d) garbage can

Now the tenth slide
Slide 10:1
Where is the mother?
a) in a police car
b) on a curb
c) in a telephone booth
d) getting into a taxi

Slide 10:2
Who does the mother call?
a) her parents
b) her boss
c) her child's school
d) the taxi company

Slide 10:3
What is she leaning on?
a) a soccer ball
b) her purse
c) a telephone book

d) the door

Slide 10:4
The phone is where, relative to the mother from the viewers perspective?
a) on the right
b) on the left
c) behind the mother
d) is not visible at all

Slide 10:5
The mother was described as
a) feeling tired
b) feeling distraught
c) running late
d) feeling anxious

Now the eleventh slide
Slide 11:1
Where is the mother now?
a) at a bus stop
b) at a taxi stand
c) at home
d) outside her office building

Slide 11:2
What is she doing at the bus stop
a) waiting for a bus
b) trying to hail a cab
c) crossing the street
d) looking for her keys

Slide 11:3
Where is she going?
a) to speak with her child's teachers
b) to pick up her other child
c) to her parent's house
d) it was not clear

Slide 11:4
What is pictured in the right foreground?
a) a stop sign
b) a bench
c) a speed limit sign
d) an approaching bus

Slide 11:5

What is the speed limit on the sign?
a) 25 mph
b) 35mph
c) 40mph
d) cannot be read

Slide 11:6
What is the number of the bus stop where she is waiting?
a) No. 3
b) No. 12
c) No. 9
d) No. 15

Appendix 4: The Toronto Alexithymia Scale (Taylor et al 1992)

In reference to the 20 question scale reported below, please indicate how strongly you agree or disagree with each proposition by placing the number that corresponds most closely with your choice in the space provided. The choice of numbers is listed below:

1= I strongly disagree. 2= I disagree. 3= I neither agree nor disagree. 4= I agree. 5= I strongly agree

Please note there are no right or wrong answers to the following items and your responses will be kept strictly confidential. Please answer the items as honestly as possible and please do not skip any items.

1. I am often confused about what emotion I am feeling
(1: strongly disagree. 2: disagree. 3: neither agree nor disagree. 4: agree. 5: strongly agree)

Response:

2. It is difficult for me to find the right words for my feelings
(1: strongly disagree. 2: disagree. 3: neither agree nor disagree. 4: agree. 5: strongly agree)

Response:

3. I have physical sensations that even Doctors don't understand
(1: strongly disagree. 2: disagree 3: neither agree nor disagree 4: agree 5: strongly agree)

Response:

4. I am able to describe my feelings easily
(1: strongly disagree. 2: disagree. 3: neither agree nor disagree. 4: agree. 5: strongly agree)

Response:

5. I prefer to analyze problems rather than just describe them
(1: strongly disagree. 2: disagree. 3: neither agree nor disagree. 4: agree. 5: strongly agree)

Response:

6. When I am upset, I don't know if I'm sad, frightened, or angry
(1: strongly disagree. 2: disagree. 3: neither agree nor disagree. 4: agree. 5: strongly agree)

Response:

7. I am often puzzled by sensations in my body
(1: strongly disagree. 2: disagree. 3: neither agree nor disagree. 4: agree. 5: strongly agree)

Response:

8. I prefer to just let things happen rather than to understand why they turned out that way
(1: strongly disagree. 2: disagree. 3: neither agree nor disagree. 4: agree. 5: strongly agree)

Response:

9. I have feelings that I can't quite identify
(1: strongly disagree. 2: disagree. 3: neither agree nor disagree. 4: agree. 5: strongly agree)

Response:

10. Being in touch with emotions is essential

(1: strongly disagree. 2: disagree. 3: neither agree nor disagree. 4: agree. 5: strongly agree)

Response:

11. I find it hard to describe how I feel about people
(1: strongly disagree. 2: disagree. 3: neither agree nor disagree. 4: agree. 5: strongly agree)

Response:

12. People tell me to describe my feelings more
(1: strongly disagree. 2: disagree. 3: neither agree nor disagree. 4: agree. 5: strongly agree)

Response:

13. I don't know what is going on inside me
(1: strongly disagree. 2: disagree. 3: neither agree nor disagree. 4: agree. 5: strongly agree)

Response:

14. I often don't know why I am angry
(1: strongly disagree. 2: disagree. 3: neither agree nor disagree. 4: agree. 5: strongly agree)

Response:

15. I prefer talking to people about their daily activities rather than their feelings
(1: strongly disagree. 2: disagree. 3: neither agree nor disagree. 4: agree. 5: strongly agree)

Response:

16. I prefer to watch "light" entertainment programs rather than psychological dramas
(1: strongly disagree. 2: disagree. 3: neither agree nor disagree. 4: agree. 5: strongly agree)

Response:

17. It is difficult for me to reveal my innermost feelings, even to close friends
(1: strongly disagree. 2: disagree. 3: neither agree nor disagree. 4: agree. 5: strongly agree)

Response:

18. I can feel close to someone, even in moments of silence
(1: strongly disagree. 2: disagree. 3: neither agree nor disagree. 4: agree. 5: strongly agree)

Response:

19. I find examination of my feelings useful in solving personal problems
(1: strongly disagree. 2: disagree. 3: neither agree nor disagree. 4: agree. 5: strongly agree)

Response:

20. Looking for hidden meanings in films or plays distracts from their enjoyment
(1: strongly disagree. 2: disagree. 3: neither agree nor disagree. 4: agree. 5: strongly agree)

Response:

Appendix 5: Heart rate baseline differences between high and low alexithymics

Introduction

Much of the research in alexithymia is laboratory based. In the laboratory, higher levels of alexithymia are often associated with higher baseline heart rate (Papciak et al., 1985; Wehmer et al 1995) and higher tonic levels of physiological arousal (Martin and Phil, 1986). It is difficult to determine from existing evidence the degree to which the observed differences in heart rate between high and low alexithymics in the laboratory are robust in terms of external validity. This is because higher baseline levels of heart rate inside the laboratory may reflect some "generalized reactivity" (Wehmer et al., 1995) to the overall experimental situation in high alexithymics rather than a higher baseline heart rate per se. For example, high alexithymics may find it more difficult to relax in the experimental environment. It has been suggested (Wehmer et al., 1995) that future work should examine heart rate and blood pressure in high and low alexithymics after a structured relaxation procedure to determine the degree to which high and low scorers respond physiologically to the experimental situation. In addition, we suggest in order to address the question of external validity of the claim that high alexithymics have higher baseline heart rate compared to low alexithymics, it is necessary to assess both subjective and physiological changes in arousal that occur over more than one laboratory session. It is possible, for example, that normal habituation to the experimental situation may occur in low alexithmic scorers reflected in subjective and physiological reduction in arousal or stress assessed at the beginning and end of a second session compared to a first session. If this habituation does not occur with high scorers, this would present convincing

initial evidence that the experimental situation itself contributes to differences in baseline heart rate in high alexithymics.

Prediction:

1. If high alexithymic participants have higher tonic levels of heart rate then low alexithymics, then high alexithymic participants will demonstrate higher baseline heart rate than low alexithymics over two sessions in the laboratory.

Procedure:

Stress and arousal checklist scores were collected for all participants (high and low alexithymics) at the beginning and end of two laboratory sessions (see chapter four for full procedure). In addition, heart rate and blood pressure were recorded at the beginning of these two sessions (again, see chapter four for the procedure used).

Results:

Subjective responses

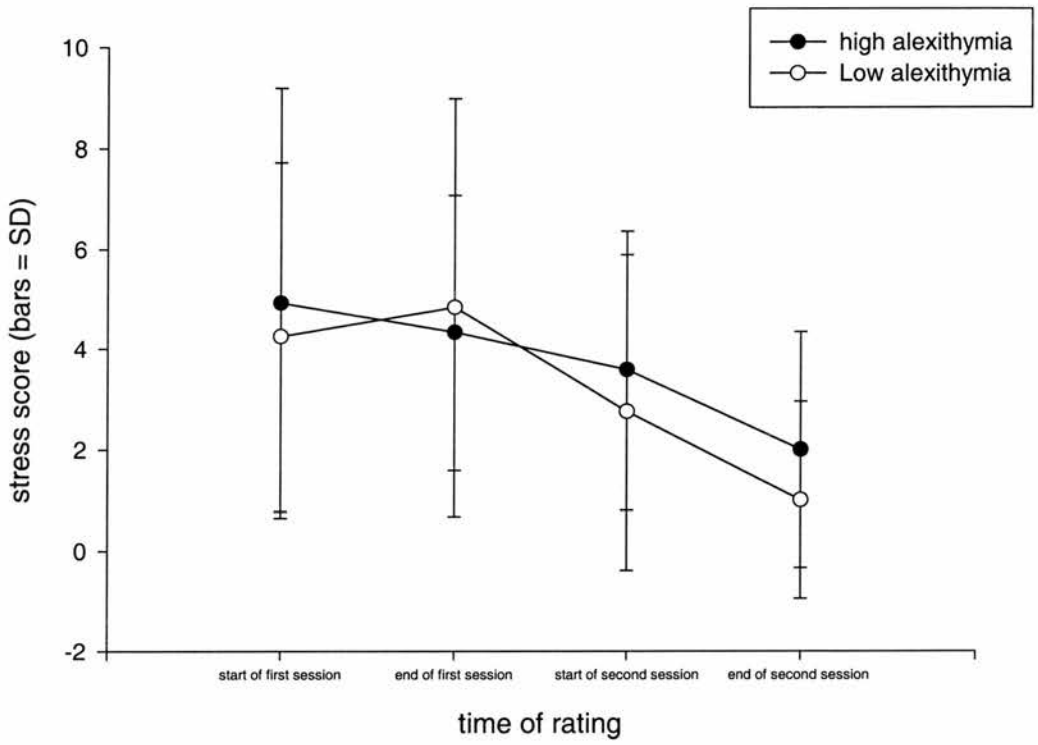
Participants in this study completed a subjective self-rating of stress and arousal at the beginning and end of both the first and second sessions. These scores are displayed in Figure A.1. (stress) and A.2 (arousal). For self- ratings of stress, Mauchly's test of Sphericity was significant for the within group variable of rating time [W (5) = .48, p = .01] and therefore, the multivariate criterion of Wilks' Lambda was used to test this variable. Repeated measures ANOVA revealed no significant effect of group [F (1, 22) = .31, p = .58], a highly significant effect of time [F (3, 20) = 15.36, p = .01] and no significant group by time interaction [F (3, 66) = .39, p = .76]. Figure 4.1 indicates that for the total sample there was no difference is stress measured at the beginning of the first session and at the end of the

first session [(time 1 and time 2) – t (23) = .00, p = 1]. There was also no significant difference between the stress ratings at the beginning of the first session and the beginning of the second session [t (23) = 1.48, p = .15]. The self-ratings of stress at the beginning of the first session (t (23) = 5.05, p = .01) and at the beginning of the second session (t (23) = 2.96, p = .01) were both significantly greater than the ratings of stress at the end of the second session in both high and low alexithymic groups to an equivalent degree (N.B. these groups were not analyzed separately).

For self-ratings of arousal, Mauchly's test of Sphericity was significant for the within group variable of rating time [W (5) = .52, p = .02] and therefore, the multivariate criterion of Wilks' Lambda was used to test this variable. Analysis of the ratings of arousal made at the start and end of both sessions revealed a significant effect of time [F (3, 20) = 5.29, p = .01], no significant effect of group [F (1, 22) = 3.74, p = .07] and no group by time interaction [F (3, 66) = .52, p = .67] – see Figure 4.2). The arousal rating made by the combined high and low alexithymia groups at the end of the second session was significantly lower than the arousal rating made at the start of the second session [t (23) = 3.79, p = .01]. No other comparisons were significant.

To summarize, the analysis of the subjective ratings revealed no differences between high and low alexithymia groups. Ratings of stress and arousal appeared to decline over time for high and low alexithymics.

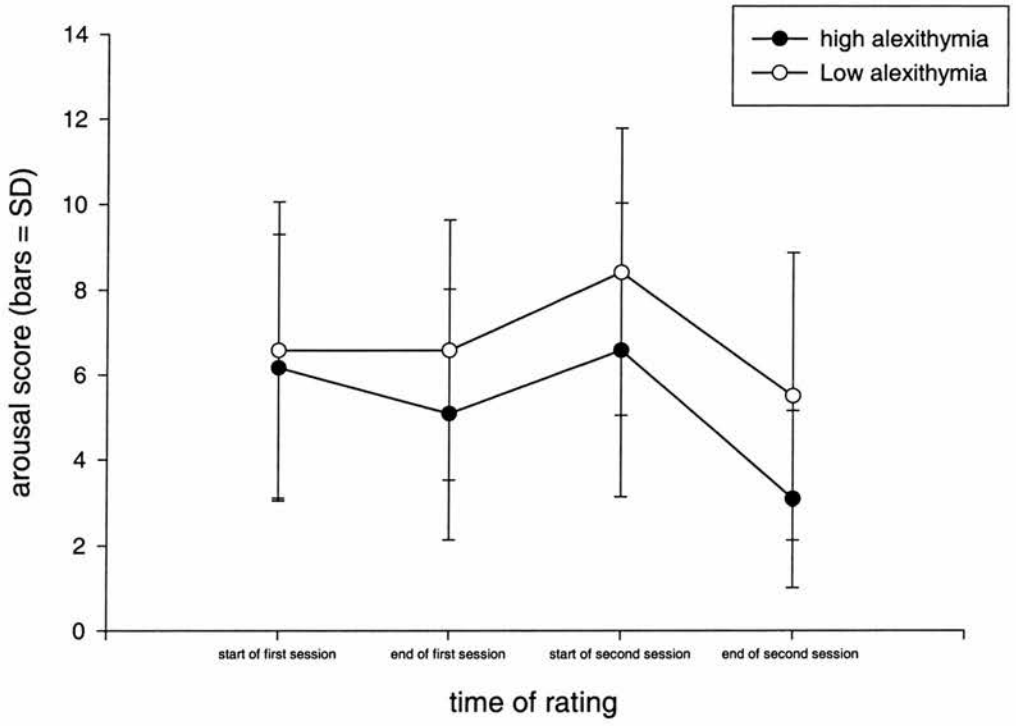
Figure A1. Self-rated stress at the start and end of two sessions



[No significant effect of group, a significant effect of time and no significant group by time interaction]

[Stress self-ratings at the start of the first session were not significantly different from stress self-ratings at the end of the first session.Stress self-ratings at the start of the first session and at the start of the second session were both significantly greater than the stress self-ratings at the end of the second session.]

Figure A2. Self rated arousal at the start and end of two sessions



[No significant effect of group, a significant effect of time and no significant group by time interaction.]

[Self-rated arousal at the end of the second session was significantly lower than the self-rated arousal at the start of the second session.]

Baseline measures of systolic and diastolic blood pressure and heart rate were recorded when participants in both high and low alexithymia groups arrived for the first session and when they arrived for the second session. These values are presented in Table A1

Table A1. Physiological indices on arrival at the beginning of the first and second sessions

Baseline physiology	Start of session 1.	Start of session 2	Group effect	Time effect	Interact.
Systolic bp					
High alexithymics	119.09 (14.11)	114.70 (19.51)	F(1,20) =.81,	F(1,20) =.04	F(1,20)=1.8
Low alexithymics	109.48 (11.20)	115.30 (13.65)	P = .38	P = .85	P = .20
Diastolic bp					
High alexithymics	59.33 (10.19)	54.44 (12.26)	F(1,20) = 2.39	F(1,20) = .00	F(1,20)=3.8
Low alexithymics	59.29 (7.38)	64.19 (7.68)	P = .14	P = 1.00	P = .07
Heart rate					
High alexithymics	79.68 (10.78)	75.48 (10.02)	F(1,20) = .00	F(1,20) = 2.2	F(1,20)=1.2
Low alexithymics	77.84 (10.17)	77.21 (6.51)	P = .99	P = .15	P = .29

Repeated measures ANOVA revealed no effect of time on systolic blood pressure, no effect of group and no group by time interaction. The same analysis of diastolic blood pressure revealed no effect of time, group and no group by time interaction. The same non-significant pattern applied to heart rate also.

Discussion

There were no significant differences between high and low alexithymics in terms of subjective ratings of stress and arousal at the beginning and end of the two laboratory

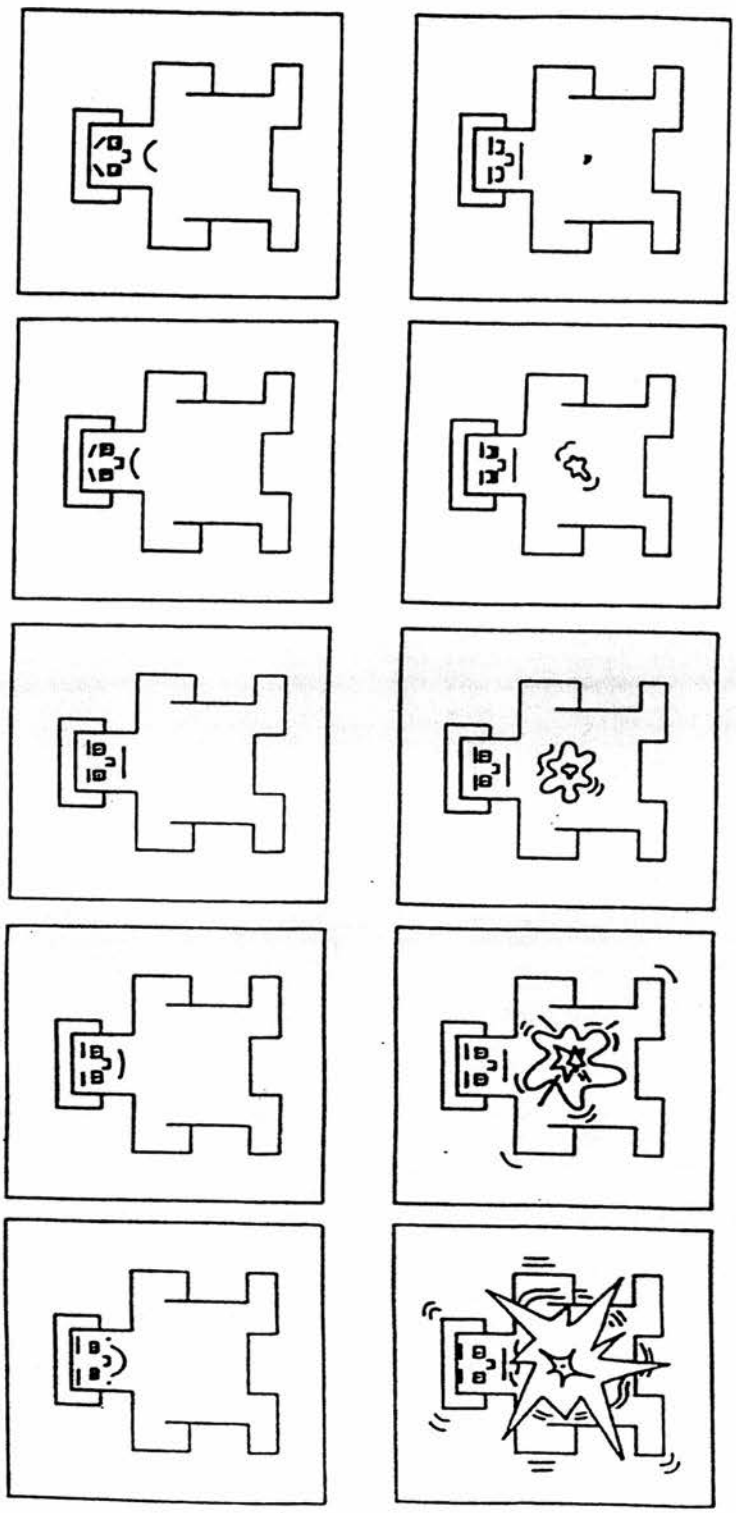
based sessions or on blood pressure or heart rate activity on arrival at both sessions. The initial prediction was that if high alexithymic participants have higher tonic levels of heart rate then low alexithymics, then high alexithymic participants would demonstrate higher baseline heart rate than low alexithymics over two sessions in the laboratory

In the laboratory, higher levels of alexithymia are often associated with higher baseline heart rate (Papciak et al., 1985; Wehmer et al 1995) and higher tonic levels of physiological arousal (Martin and Phil, 1986). It is difficult to determine from the existing evidence the degree to which the observed differences in heart rate between high and low alexithymics in the laboratory have external validity. This is because higher baseline levels of heart rate inside the laboratory may reflect some "generalized reactivity" (Wehmer et al., 1995) to the overall experimental situation in high alexithymics rather than a higher baseline heart rate per se.

This study has gone some way towards addressing the problem of external validity. It has examined heart rate and blood-pressure in high and low alexithymics after a structured relaxation procedure (see chapter 4) to determine the degree to which high and low scorers respond physiologically to the experimental situation. It has found no differences in physiological variables of blood pressure or heart rate in high and low alexithymics during relaxation in the laboratory. In addition, we attempted to address the question of external validity of the claim that high alexithymics have higher baseline heart rate compared to low alexithymics, by assessing both subjective (Figures A1 & A2 and physiological Table A1 changes in arousal that occur over more than one session. We found equal habituation in subjective responses of stress and arousal to the experimental situation in low and high scorers on the TAS-20 (Figures A1 & A2). In addition we have found no differences between high and low scorers in terms of blood pressure and heart rate

recorded on arrival at the first compared to arrival at the second session (Table A1). This finding is at odds with previous research demonstrating higher baseline heart rate (Papciak, 1985; Wehmer et al 1995) and higher tonic sympathetic arousal (Martin & Phil., 1986) in high versus low alexithymics. If habituation had not occurred with high scorers, this would have presented convincing initial evidence that the experimental situation itself contributes to differences in baseline heart rate in high alexithymics. In the light of the present findings, baseline heart rate and subjective stress and arousal in high scorers is no different from that displayed by low scorers. Both show the gradual decrease over time in subjective feelings, to a similar degree, while maintaining similar levels of blood pressure and heart rate over baseline recordings. This study employed a relatively new method of recording blood pressure and heart rate that may also allow for a more realistic and externally valid method of measuring baseline or tonic levels of physiological arousal in alexithymics. The Portapress method is relatively self-sufficient and 'experimenter free' allowing for the possibility of future ambulatory monitoring of blood pressure and heart rate outside the laboratory. This would represent an improvement on the current method, which has, using the same apparatus, provided data over more than one session to measure habituation. Ambulatory monitoring could further clarify the external validity of the claim of higher baseline heart rate in alexithymia.

Appendix 6: The self assessment manikin used for the self-ratings of valence (left hand hand column) and arousal (right hand column) (from Lang et al., 1999).



Appendix 7. Congruence study: Stimulus set.

IAPS: International Affective Picture System
BBC: British Broadcasting Corporation sound effect CD range (Stirling Uni Film & Media dept)
FX: FX sound effect CD range (Stirling Uni Film and Media dept)

Categories:	**HVLA:**	High Valence Low Arousal
	HVHA:	High Valence High Arousal
	N:	Neutral
	LVHA:	Low Valence High Arousal
	LVLA:	Low Valence Low Arousal

- 25 target images in 5 categories with either congruent or incongruent accompanying sounds (for rating and physiological recording at presentation).
- 25 distracter images in 5 categories with either congruent or incongruent accompanying sounds. (for recognition memory test at 7 days).
- Presentation consists of 25 trials of either images or sounds alone or in combination, test consists of 50 trials of either images or sounds alone or in combination.
- 5 groups: Image alone (IAPS image alone); congruent sound alone (IAPS accompanying congruent sound only); incongruent sound alone (IAPS accompanying incongruent sound only); congruent sound & image (IAPS image and accompanying congruent sound); incongruent sound & image (IAPS image and accompanying incongruent sound). Stimulus materials presented to groups are drawn from following:

Low valence, high arousal.

Congruent targets			**Incongruent targets (HVLA)**
IAPS image code		(sound file name & CD code)	Sound file name (& CD code)
1300	Dog	(Bark BBC6, 7)	Trot (FX2, 67)
3250	Chest	(hosp. FX1, 23)	Fair (FX4, 7)
6550	Knife	(struggle FX5, 55)	eggs (FX2, 45)
6821	Gang	(siren FX1, 25)	cycling (FX4, 40)
2800	Boy	(man cry FX5, 3)	laugh (FX5, 2)

Congruent distracters			**Incongruent distracters (HVLA)**
IAPS image code		(sound file name & code)	Sound file name (& code)
9630	Abomb	(quarry BBC18, 18/19)	hiccups (FX8, 23)
9620	(9600) ship	(horn FX1, 33)	sheep FX2, 69. Sigh (FX2, 14)
6370	mask	(breath FX5, 12)	snore (FX5, 12)
6312	abduc	(screams FX5 49)	rowboat (fx4, 27)
9921	Fire	(FX5, 76)	brook (BBC11, 1)

Low valence, low arousal

Congruent targets			**Incongruent targets (HVHA)**
IAPS image code		(sound file name & code)	Sound file name (& code)
6010	prisoner	(handcuff FX5, 96)	concert (FX4, 25)
9001	graveyard	(church bells FX1, 37)	motor racing (BBC17, 29)
9390	dishes	(washingup FX2, 48)	ski (BBC17, 35/36)
9110	Petrol	(lorrygarrage FX1, 75)	squash (FX4, 55)
9331	bum	(drinking BBC8, 26)	pillowfight (FX5, 57)

Congruent distracters			**Incongruent distracters (HVHA)**
IAPS image code		(sound file name & code)	Sound file name (& code)
2590	oapfemale	(washingmachine FX2,49)	grouplaugh (FX5, 42)
9290	rubbish	(garbagepress FX3, 33)	faststeamtrain (FX1, 94/95?)
9280	industry	(Factory FX3, 30)	ticklingchild (FX5, 44)
9010	barbed wire	(Wind FX2, 54)	fireworks (FX4, 3)
2206	finger print	(typewriter FX3, 53)	Flipper/arcade (FX4, 4/FX4, 6)

Neutral

Congruent targets			**Incongruent targets (N)**
IAPS image code		(sound file name & code)	Sound file name (& code)
7550	computer	(printing FX3, 72)	microwave (FX2, 35)
6900	jet	(passing jet FX1, 88)	car engine (FX1, 57)
5900	route 66	(Harley FX1, 77)	xerox machine (FX3, 67)
7503	cards	(roulette FX4,9)	bathtub (FX2, 22)
7510	city	(intersection FX1, 1)	wavesonbeach (FX2, 59)

Congruent distracters			**Incongruent distracters (N)**
IAPS image code		(sound file name & code)	Sound file name (& code)
2702	womaneat	(crunch FX5, 24)	billiards (FX4,12)
2600	pint	(bottledrink FX5, 21)	drum roll (FX5, 82)
1560	Hawk	(lapwing BBC12,7)	teethbrush (FX2,20)
7020	Fan	(whir FX2, 15)	clocktick (FX2, 5)
2381	phone	(ring FX3,83)	slide projector (FX3, 45)

High valence, low arousal

Congruent targets			**Incongruent targets (LVHA)**
IAPS image code		(sound file name & code)	Sound file name (& code)
1620	springbok	(savanahsounds BBC6,44)	firetrucksiren (FX1,27)
7325	girl&melon	(lawnmower FX2, 95)	dragon (BBC8, 83)
5780	Tropforest	(nightgale FX2, 79 or forest FX2,91)	freezing (FX5, 15)
1900	anenome	(waves on beach FX2,59)	explosions (FX5,75)
2560	familypicnic	(chatting FX5, 47)	roar (FX2, 73)

Congruent distracters			**Incongruent distracters (LVHA)**
IAPS image code		(sound file name & code)	Sound file name (& code)
1602	butterfly	(latespring midday BBC15 4/5)	machine gun (FX5,72 last)
2530	cyclists	(pedaling FX4, 40)	thunder (FX2,55)
5410	violinist	(applause FX4,24)	whinny (FX2,66)
5220	woodbridge	(blackbird BBC12,1)	rattlesnake (FX2, 78)
2791	balloons	(fairground FX4,7)	policesiren (FX1, 25)

High valence, high arousal

Congruent targets			**Incongruent targets (LVLA)**
IAPS image code		(sound file name & code)	Sound file name (& code)
8180	cliffdiving	(waterfall FX2, 58)	toilet (FX2, 21)
8200	waterski	(boatmotor FX4,31 lastversion)	dirtydishes (FX2,48)
8300	maninplane	(biplane FX1, 86)	pigs (FX2, 72)
8501	money	(cash register FX1, 48	Fly (FX2, 90)
8490	rollercoaster	(people on roller FX4, 8)	loons (FX2, 85)

Congruent distracters			**Incongruent distracters (LVLA)**
IAPS image code		(sound file name & code)	Sound file name (& code)
1811	chimps	(panthoots FX2, 75)	rain (FX2, 56)
8120	tennis	(tennis sounds FX4,53)	rockdrill (FX3, 35)
8260	motorcycle	(motorcyclerace FX4, 75)	breakingcarwindow (FX5, 60)
8030	skijump	(sled FX4,43)	junkyard (FX5, 61)
8460	runner	(sprint passage FX4, 89)	slurping (FX5, 19)

Appendix 8: Subjective arousal ratings of stimulus categories by group. Results of the One-way ANOVA performed following the significant category by group interaction (Figure 5.1. – Chapter 5)

One-way ANOVA on category by group (df 4, 56, ar = arousal rating):

LVHAar: (F = .86, p = .50)
LVLAar: (F = 3.66, p = .01) **- Post Hoc LSD** = Grp3 > grp1 (p = .03), grp5 > grp1 (p = .01), grp5 > grp4 (p = .01)
Neutar: (F = 3.24, p = .02) - Grp2 > grp1 (p = .01) & grp4 (p = .04). Grp3 (p = .01) & 5 (p = .03) > grp1.
HVLAar: (F = 10.4, p = .01) - Grp2 > grp1 (p = .01) & grp4 (p = .01). Grp5 > grp2 (p = .02), 1, 3 & 4 (p = .01).
HVHAar (F = 3.81, p = .01) - Grp1 (p = .02), grp3 (p = .01) & grp4 (p = .03) > grp2.

Appendix 9: Subjective valence ratings for stimulus categories by group. Results of the One-way ANOVA perfromed following the significant category by group interaction (Figure 5.2 – Chapter 5)

One –way ANOVA on category by group (df 4, 56, vr = valence rating)

LVHAvr: (F = 5.67, p = .01). **Post Hoc LSD** - Grp2 > grp1 (p = .01). Grp5 > 1, 3 & 4 (p = .01).
LVLAvr: (F = 10.12, p = .01). Grp 2 > 1&4 (p = .01), 3&5 (p = .03). Grp5 > grp2 (p = .03), 1, 3 & 4 (p = .01).
Neutvr: (F = 3.22, p = .02). Grp3 & 4 > grp2 (p = .01).
HVLAvr: (F = 1.13, p = .35).
HVHAvr: (F = 9.98, p = .01). Grp1 > grp2 & 5 (p = .01). Grp3 > grp2 & 5 (p = .01). Grp4 > grp2 & 5 (p= .01).

Appendix 10: Error rates by category of image in the recognition memory test for lateral presentations used in chapter 6.

Brief lateral presentations: Errors made to each category of image in the recognition memory test (See Figure A3.)

All participants; patients and controls, were presented with a series of images, which varied in rated valence and arousal for 80 milliseconds each on either the left or the right of a central fixation point. Memory for these images was later assessed via a free recall assessment and a recognition memory (reaction time) test. In the reaction time test participants were required to respond to the question 'have you seen this image briefly presented before' A series of images were presented in a central position on the screen for recognition that either had or had not been briefly presented on either the left or the right of central fixation point. The free recall assessment took place before the recognition memory assessment and involved participants describing in as much detail as possible any images they remembered being 'flashed briefly' prior to a filled half- hour delay.

An analysis of the percent of responses that were errors in the recognition memory test for the previously presented images reveals that the patient DR failed to respond correctly to any of the images in the two extreme arousal categories (regardless of valence). Error rates for the low valence, high arousal category and error rates for the high valence high arousal category were at ceiling for DR. In addition, for the low valence high arousal category of images, the patient SE's performance was at chance (error rate = 50%). In contrast, the error rates of controls were below chance for both the low valence high arousal category and the high valence, high arousal categories (i.e. participants were making more errors than correct responses in these two categories). Error rates were consistently lower for all participants to an equivalent

degree in low arousal categories (regardless of valence). Modified paired sample t-tests revealed that the only significant difference between controls and patients occurred in recognition error rates to the neutral category of images briefly presented before. The patient SE produced a significantly higher error rate compared to controls in this neutral category [t (9) = 2.28, p = .04].

Figure A3 Error rates (by category of image) in the recognition memory test for lateral presentations