

Understanding Emotional Memory: Cognitive Factors

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List of Abbreviations

ABC – arousal biased competition [model]

ACC – anterior cingulate cortex

dACC – dorsal anterior cingulate cortex

ALE – activation likelihood estimation

AMY – amygdala

AnG – angular gyrus

ANOVA – analysis of variance

ATL – anterior temporal lobe

BESA – brain electrical source analysis

BOLD – blood oxygen level dependent

CMS – common mode sense

DA – divided attention [task]

DAN – dorsal attention network

dHb – deoxygenated haemoglobin

Dm – differential of memory, difference due to memory

DP – distinctiveness processing

DRL – driven right leg

ED – edge density

EEG - electroencephalography

EEM – emotional enhancement of memory effect

iEEM – immediate emotional enhancement of memory effect

EOG - electrooculogram

ERP – event-related potential

FC – feature congestion

FEF – frontal eye field

fMRI – functional magnetic resonance imaging

FWE – family wise error

GANE - Glutamate Amplifies Noradrenergic Effects [model]

GAPED – Geneva affective picture database

GLM – generalised liner model

HPC – hippocampus

aHPC – anterior hippocampus

HSD – honestly significant difference

IAPS – international affective picture system

IFG – inferior frontal gyrus

IPS – intraparietal sulcus

LSA – latent semantic analysis

LBC_{sem} – list based semantic clustering index

LOC – lateral occipital cortex

LPP – late positive potential

MFG – middle frontal gyrus

MNI – Montreal neurological institute

MT+ - middle temporal complex

MTL - medial temporal lobes

mV - microvolts

NAPS - Nencki affective picture system

NE - norepinephrine

NMR - nuclear magnetic resonance

PANA - positive activation negative activation [model]

PFC - prefrontal cortex

dIPFC - dorsolateral prefrontal cortex

dmPFC - dorsomedial prefrontal cortex

mPFC - medial prefrontal cortex

vIPFC - ventrolateral prefrontal cortex

PHC - parahippocampus

pPHC - posterior parahippocampus

PPL - posterior parietal lobule

PSP - post-synaptic potential

PTSD - post-traumatic stress disorder

RT - reaction time

rTMS - repeated transcranial magnetic stimulation

sAA - salivary alpha-amylase

SAM - self assessment manikin

SE - subband entropy

SeRENS - semantically related emotional and neutral stimuli

SLIMM - schema-linked interactions between medial prefrontal and medial temporal regions

SME - subsequent memory effect

SMG - supramarginal gyrus

rSMG - right supramarginal gyrus

SNR - signal to noise ratio

SPM - statistical parametric mapping

SSP - signal source projection

STG - superior temporal gyrus

aSTG - anterior superior temporal gyrus

SVD - singular value decomposition

SW - slow wave

TPJ - temporal parietal junction

VAN - ventral attention network

VC - visual complexity

WM - working memory

Understanding Emotional Memory: Cognitive Factors

Submitted for the degree of PhD Psychology to the University of Manchester; by
Gemma Elizabeth Barnacle on Monday 28th September 2015.

The term Emotional Enhancement of Memory (EEM) describes the better memory of emotional compared to neutral events. When the EEM effect is measured after a delay the modulation model explains this effect very well, citing preferential consolidation of emotional events as the cause. However, the EEM effect can be observed before consolidation, an inexplicable result for the modulation model. Mediation theory offers an alternative explanation of the EEM effect: cognitive factors at encoding contribute to the immediate EEM (iEEM); namely attention, semantic relatedness, and distinctiveness processing (DP). The current research sought to further elucidate the neural underpinnings of DP – said to occur in ‘mixed’ lists of emotional and neutral stimuli – as a significant contributor to the iEEM. This was measured by comparing immediate free recall memory of emotional and neutral stimuli presented in *mixed*, and *pure* lists (emotional *or* neutral stimuli), using a specially formulated stimulus set which controlled for differential semantic relatedness (SeRENS, Chapter 3).

Electroencephalography (EEG) and functional magnetic resonance imaging (fMRI) data provided preliminary evidence of neural encoding correlates of the iEEM (Chapter 4 and 5); data which is not predicted by the modulation model. The behavioural EEM effect found in mixed lists was driven by a reduction in *neutral* memory relative to pure lists; however neural correlates of this effect were minimal. Conversely, successful mixed list emotional encoding (relative to pure list emotional encoding and neutral encoding) correlated with greater neural activity associated with [bottom-up] attention (in P300 and right supramarginal gyrus) and semantic processing (late positive potential and left anterior superior temporal gyrus; EEG and fMRI evidence respectively); although this did not correlate with behavioural measures of memory. This behaviour-neuroimaging discrepancy can be reconciled when one considers the results of Chapter 6: the crucial iEEM behavioural effect of impaired neutral memory was associated with retroactive interference from preceding emotional stimuli (especially when relational processing resources were depleted); a neural effect that cannot be captured by the current event-related designs. This suggests that what is captured in the neuroimaging data is the mechanism which drives the retroactive interference at the temporal locus of emotional stimulus onset.

These results raise the possibility of two dissociable EEM effects: the iEEM effect explained by poor neutral memory due to retroactive interference of preceding emotional stimuli (mediation theory); and the delayed EEM effect explained by preferential emotional stimulus consolidation (modulation model). These explanations can be unified into one model; however further testing would be required to determine the endurance of cognitive contributions to the EEM effect.

Declaration

One third of the data referred to in Chapter 4 was submitted in support of an application for Master of Science in Cognitive Brain Imaging at the University of Manchester in 2012. These data have been very substantially re-analysed and re-interpreted for the current submission.

No other portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

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Alternative Format Rationale

This PhD is submitted in alternative format. As such, each of the experimental chapters (chapters 3, 4, 5, 6) have been prepared for submission as stand-alone journal articles. The author of the PhD is the first author on all work submitted in this thesis (for co-authors see below). It is expected that all experimental chapters of the thesis will be submitted for publication shortly after the completion of the PhD.

To aid in the conceptualisation of the PhD thesis as a whole, the thesis also contains general chapters (chapter 1, 2, 7), which are not intended for submission as stand-alone journal articles.

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**indicates joint senior authorship*

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The Author

Gemma Barnacle completed a BSc (Hons) Psychology at the University of Kent in 2007. During this time and subsequently she pursued clinical roles, working in the field of substance misuse and addictions rehabilitation. In 2011, Gemma began training as a mental health nurse at the University of Chester, and left with a Certificate of Higher Education in Healthcare Studies. Her move brought her to Manchester where she has lived since, whilst completing a MSc Cognitive Brain Imaging, and the current PhD Psychology; both of which were funded by a 3+1 Economic and Social Research Council Studentship.

During the PhD Psychology Gemma was successfully awarded a competitive scholarship from the Deutscher Akademischer Austauschdienst (DAAD; German Academic Exchange Service), which afforded her the opportunity to live and work in Germany for 6 months, conducting her own fMRI experiment at the Department of Systems Neuroscience, Universitätsklinikum, Hamburg-Eppendorf.

1. General Introduction

Overview

The investigation of the Emotional Enhancement of Memory (EEM) is concerned with understanding how and why emotional events are remembered better than neutral events. For example, research has investigated the EEM in animals (de Quervain, Roozendaal, & McGaugh, 1998; Gold, Hankins, Edwards, Chester, & McGaugh, 1975; McIntyre, Hatfield, & McGaugh, 2002; Roozendaal, 2000), and humans (Kensinger & Corkin, 2004; Rozenkrants & Polich, 2008); using memory tests such as recognition (Mickley Steinmetz & Kensinger, 2009; Weymar, Löw, Melzig, & Hamm, 2009) or free recall paradigms (Cahill et al., 1996; Pottage & Schaefer, 2012; Talmi, Schimmack, Paterson, & Moscovitch, 2007; Watts, Buratto, Brotherhood, Barnacle, & Schaefer, 2014); and at different test latencies: before and after consolidation (Bradley, Greenwald, Petry, & Lang, 1992; Kleinsmith & Kaplan, 1963; Wolf, 2012); for reviews see McGaugh (2004), and Tully and Bolshakov (2010).

One influential model of the EEM effect – the modulation model (McGaugh, 2004), based primarily on animal investigation (Cahill & McGaugh, 1998; McGaugh, 2004) has also received much support from human research (e.g. Groch et al., 2011; Kensinger & Corkin, 2004; Kroes, Strange, & Dolan, 2010; Ritchey, LaBar, & Cabeza, 2010; Schwarze, Bingel, & Sommer, 2012; Sharot, Verfaellie, & Yonelinas, 2007; Strange & Dolan, 2004; for reviews see Dolcos, Denkova, & Dolcos, 2012; Phelps & LeDoux, 2005). This model clearly cites [synaptic] consolidation (which the modulation model suggests takes an appreciable time to manifest: hours to days) as a key process in the EEM effect, however behavioural research provides clear evidence

of an ‘immediate’ EEM – before consolidation (LaBar & Phelps, 1998; MacKay et al., 2004; Talmi, Luk, McGarry, & Moscovitch, 2007; Talmi & McGarry, 2012; Watts et al., 2014). Importantly, we refer to the immediate EEM as occurring *before* consolidation; however we acknowledge that consolidation processes have at least begun at encoding. Also, given that the timecourse of for the completion of consolidation processes is not clearly defined, we use the term ‘before consolidation’ with caution.

This immediate EEM effect has been explained by cognitive factors (Mediation Theory; Talmi, 2013): In brief, mediation theory states that emotional stimuli (compared to neutral stimuli) may preferentially recruit cognitive resources such as attention, semantic relatedness and distinctiveness processing at the time of encoding and / or retrieval, which contributes to the (immediate) EEM effect. It is the aim of this thesis to develop a neuroscientific understanding of the immediate EEM, and to better characterise the cognitive factors contributing to this effect using behavioural and neuroimaging investigations – information that is crucially lacking in the extant research. It is hoped that this work could provide a basis for future research comparing neural correlates of the EEM effect before and after consolidation; which would aid in the identification of the respective temporal- and spatial- sources, and latencies of these hitherto independently researched cognitive and consolidation effects. Although outside of the scope of empirical investigation within this thesis, the theme of a unified model of EEM runs throughout, and is discussed extensively.

The introduction to the literature that follows here will first outline definitions of pertinent terms, followed by a brief review of the modulation model and a brief summary of existing neuroimaging research of the EEM effect in the neuroimaging modalities which will be used in this body of work (namely electroencephalography, EEG; and functional magnetic resonance imaging, fMRI). Next the alternative

explanation of the EEM offered by mediation theory will be examined. Special consideration will be afforded to the cognitive factor distinctiveness processing, which is of particular interest to this body of work.

1.1. Definitions

1.1.1. Emotion

It would seem intuitive that emotion should be an easily definable term; however the problem of defining emotion *scientifically* has been a challenge for the field of Psychology for many years (Izard, 2010). Two particular problems with defining emotion have received considerable debate: 1) identifying the bodily origin of the subjective experience of emotion, and 2) reliable situational predictors of emotion.

While early theorists (e.g. James, 1884) reduced emotions to their physical manifestations (such as visceral changes) in the body, citing these physical symptoms as the origin of emotions; this was later disputed, and a shift towards a neural origin was postulated (Cannon, 1927). This notion has gained momentum throughout many decades, especially with the advent of modern neuroimaging techniques. Many modern theories of emotion now acknowledge a neural basis of emotion, whilst recent psychological influence has added cognitive and environmental factors as contributors (Lazarus, 1991a, 1991b; Schachter & Singer, 1962) to create a more holistic approach to defining emotions. In essence, these models propose that interactions of the situation (environment); our appraisals of- and motivations towards the situation (cognition); and – to some degree – our bodily responses (physiology) contribute to the complex formation and experience of emotion.

Given this complex explanation of the origins of emotion, the problem remains of what factors (if any) are sufficient and necessary to reliably induce emotion. To answer this question, research draws upon the literature regarding the existence of basic emotions: In opposition to the proponents of discrete emotions (for whom all emotions and emotional states are distinct and have no overlapping qualities), many psychologists subscribe to the idea that emotions (and emotional states) can be reduced to something more 'basic', or general. This idea has been employed to infer the existence of broad emotional states (Ekman, 1992) such as happiness / sadness to which other more specific emotions may be generalised (e.g. elation, surprise / grief, despair); and of general dispositions (approach /avoidance; Barrett & Wager, 2006; Wager, Phan, Liberzon, & Taylor, 2003), or dimensions (arousal / valence) to which emotions can be 'mapped'. The latter dimensional explanation of emotion has received considerable attention, producing a number of theoretical models such as the circumplex model of emotion (Posner, Russell, & Peterson, 2005; Russell, 1980); dimensional models e.g. the positive activation - negative activation model ([PANA]: Watson & Tellegen, 1985); and vector models (Bradley, Greenwald, Petry, & Lang, 1992; Greenwald, Cook, & Lang, 1989). Such dimensional models purport that emotion can be reduced to two dimensions: namely arousal (a measure of intensity) and valence (a measure of pleasantness, often referred to as 'positive' and 'negative'); and have been extensively investigated (Dolcos, LaBar, & Cabeza, 2004; Ihssen & Keil, 2013; Kensinger, 2004; Kensinger & Corkin, 2004; Mickley Steinmetz, Addis, & Kensinger, 2010; Mneimne et al., 2010; Rubin & Talarico, 2009). As such, the current research will define emotion along the two dimensions of arousal and valence; although it should be noted that we do not discount other theoretical accounts, and we acknowledge challenges to this account, e.g. the problem of mixed emotions

(Berrios, Totterdell, & Kellett, 2015; Larsen, McGraw, & Cacioppo, 2001; Schimmack, 2001).

1.1.2. Memory

Memory is a phenomenon with a long history of investigation. Advancing from the early philosophical accounts of Aristotle and others, modern accounts of memory are additionally supported by empirical data, and reflect a constellation of distinguishable processes. These processes of memory are defined based on many factors such as: the duration of memory (short, long, working memory); memory content (semantic, episodic, autobiographical, and prospective memory); associated brain regions or networks (e.g. those specific to kind of memory such as recall or familiarity, and the kind of information such as motor-, spatial-, or emotional memory); and the methods by which memory is tested (e.g. free/cued recall, forced-choice, or yes/no). Research has also very clearly delineated the stages of memory to include encoding, storage, consolidation, and retrieval. These are just some of the ways in which memory can be referred to, but of particular importance to this body of work are the memory *processes* involved in encoding and retrieval; and the method of assessing memory that uses free recall.

Encoding refers to the processes (both psychological and neural) that begin at the instant at which an event or stimulus is perceived and are said to represent the acquisition of information (Ashcraft & Radvansky, 2010). By extension, retrieval refers to the act of accessing this previously acquired information. Free recall in particular may be thought of as the experimental method of prompting memory in the way most similar to every-day retrieval. Free recall is spontaneous and

unconstrained, i.e. the participant generates the memory output themselves without any specific cues or direction (although this may be manipulated experimentally). This differs from other tests of memory such as recognition memory which involves the presentation of a test-stimulus to which the participant is prompted to make a memory judgement. The different properties and processes of these two kinds of retrieval have been well described e.g. by Shiffrin and colleagues (Malmberg & Shiffrin, 2005; Raaijmakers & Shiffrin, 1990; Shiffrin & Steyvers, 1997; Shiffrin, 2003). For free recall it is suggested that retrieval begins with an initial context cue that identifies the 'episode' from which to subsequently search for appropriate memories. When an item is selected from memory, this becomes the new cue for a further search to 'find' other appropriate memories. This process continues until the current cue is exhausted, and a new context cue is generated from which follows further item search and selection (Shiffrin, 2003). For an evaluation of the use of this test of memory see Section 2.1.2 of the General Methodology.

1.1.3. Cognition and cognitive factors

According to one definition, cognition refers to "all the processes by which the sensory input is transformed, reduced, elaborated, stored, recovered, and used" (Neisser, 1967). Of particular importance to this body of work are the cognitive processes of semantic relatedness and distinctiveness processing; as these factors are key components of mediation theory.

Importantly, both semantic relatedness and distinctiveness may be considered properties of the stimulus, or as processes themselves. In terms of stimulus

properties, to paraphrase Tulving (1979), broadly speaking semantics refers to the knowledge or understanding of an item or event. By extension of this, the term semantic *relatedness* may be used to refer to a shared meaning or understanding of two (or more) items or events. Distinctiveness, as defined by Schmidt (1991) may be thought of as primary (a stimulus distinct from those held in working memory, i.e. other stimuli from the same list) or secondary (a stimulus that is distinctly different from our world view, i.e. from every day encounters). For example, a stimulus may be designated as distinctive due to its brightness of colour; and two or more stimuli may be designated as semantically related because they both fit the theme of 'holiday'; so far neither definition speaks of a cognitive process.

Although semantic relatedness and distinctiveness may be objectified in this manner, it is the assessment and processing of these stimulus attributes that constitute the underlying cognitive processes, which is the focus of the ensuing investigations. Stimulus properties and cognitive processes of these kinds can be readily distinguished using a simple example: Two stimulus categories are formed containing four words each – category 1: Beach, Ball, Sun, Sand; category 2: Pencil, Pen, Paper, Eraser. Stimuli within both categories demonstrate objective properties of high semantic relatedness, and both categories are objectively distinct from each other. However, it is necessary for a participant naïve to these controls to assess each stimulus in turn to determine the status of each stimulus as they relate to these two properties: semantic relatedness and distinctiveness. This requires semantic *processing* of each stimulus to determine its categorical membership, and distinctiveness *processing* to determine if there is more than one distinct category. These are the cognitive processes as dissociated from the properties of a stimulus; of which the former is of most interest to the current research.

Specifically, Hunt and McDaniel (1993) refer to distinctiveness processing as the cognitive process which enables the assessment of common and non-common properties amongst items, achieved optimally using item-specific- and relational-processing. The assessment of commonality of properties amongst items (common, non-common) may be considered as two sides of the same coin – the proportion of commonality among a group of items is necessarily inversely related to the proportion of non-commonality. (N.B. this is true when one assesses commonality for *one* characteristic of the items at a time. E.g. when assessing words, the font colour of words can be the same or different but not both; but when a second factor word length is introduced, an item may be both similar in font colour and different in word length). This notion is elegantly captured in Nairne’s (2001) model, which states that successful memory is dependent on the relationship between E and X, where E is the event and X is the cue to remember this event. Successful retrieval of E will depend on how many characteristics E and X share, and how dissimilar X is from other events to be recalled. When a given X relates to many events this is inversely proportional to successful retrieval (cue overload). This definition of distinctiveness processing may be seen as a logical extension of the term ‘primary distinctiveness’.

It is important to stress here that distinctiveness processing is a psychological construct, and therefore is not itself a directly measurable process. At best, the current experiments aim to measure behaviour and neural responses during circumstances that are said to induce distinctiveness processing by manipulating the type of list composition (e.g. encoding lists of intermixed stimuli from two categories to create “mixed” lists, compared to “pure” lists containing stimuli of only one category); which we hope will shed light on the mechanisms that underlie this cognitive process, and how it contributes to the EEM effect.

1.2. How the modulation model explains the EEM effect: Consolidation

The Modulation Model pioneered by McGaugh (2004) embodies extensive results focussing on the EEM effect based on neurochemical processes at the stage of synaptic consolidation. Evidence in support of the modulation model comes from a diverse range of studies over a span of several decades, with a particular focus on animal studies (e.g. Chavez, McGaugh, & Weinberger, 2009), but also in humans (e.g. Labar, Gatenby, Gore, Ledoux, & Phelps, 1998; Zeidan et al., 2011), and utilising a range of experimental manipulations such as electrical and magnetic stimulation (e.g. Balconi & Ferrari, 2012), drug infusions (e.g. Dèbiec, Bush, & LeDoux, 2011), and lesion studies (e.g. Phelps, Labar, & Spencer, 1997). The following paragraphs present a summary of the mechanisms of the modulation model and brief details of further supporting evidence.

In brief, the modulation model is principally concerned with the functional connection of the amygdala (AMY), hippocampus (HPC) and caudate nucleus which are said to perform different functions. The amygdala is said to be the modulatory hub which influences brain regions, e.g. particularly the hippocampus and the caudate nucleus. Activation of the amygdala may be achieved by several routes, but most commonly cited are the actions of stress hormones such as epinephrine and cortisol. The levels of these hormones may rise due to a stress reaction (for example witnessing a traumatic event), or may rise due to experimental drug administration. Epinephrine activates the amygdala indirectly as it cannot permeate the blood brain barrier. It is proposed that peripheral elevation of these hormones (for example during a stress response) leads to the activation of beta-adrenoceptors on the vagus nerve, which connects via the nucleus of the solitary tract (Miyashita & Williams,

2006) and the locus coeruleus (McIntyre, McGaugh, & Williams, 2012) to the amygdala which in turn releases norepinephrine (NE). This proposed mechanism was further supported by research that showed a positive correlation between salivary alpha-amylase (sAA) – a biomarker for noradrenergic activity – and selective subsequent emotional memory enhancement (Segal & Cahill, 2009).

McIntyre et al., (2002) showed that when tested thirty minutes after inhibitory avoidance training; rats demonstrated a 300% increase of NE in the amygdala compared to baseline. The magnitude of NE increase in individual rats predicted inhibitory avoidance performance after 24 hours, suggesting dose-dependent NE as a key component in the memory of emotional events (greater NE increase from baseline correlated with greater memory). One limitation of this study is that it did not test memory at different time intervals. This is of interest because the mechanisms of EEM as defined by the modulation model are said to manifest a behavioural EEM effect *only* after consolidation. To this end, a comprehensive study by Ellis & Kesner (1983) showed that a large dose of NE administered to the amygdala immediately after training resulted in the greatest impairment of avoidance behaviours when tested after 24 hours, (these rats showed less behavioural signs that they remembered the previous footshock). Importantly, this effect was found to be time and dose dependent. If a smaller dose of NE was administered (while all other conditions remain the same) their behaviour suggested that their memory was preserved. Compared to the 24 hour test group, there were no memory effects found when passive avoidance was tested 30 minutes after footshock; suggesting that the effects of NE require a greater length of time to become manifest.

Another stress hormone – Cortisol – may act directly on the amygdala, or indirectly by inducing the release of glucose from the liver which is associated with

improved memory (again with modulatory dose- and time- dependent effects). For example stress induced cortisol elevations have been demonstrated to selectively enhance memory: e.g. for negatively valenced words when memory was tested after 1 hour (Schwabe, Bohringer, Chatterjee, & Schachinger, 2008); and for negative images when tested after 2 days (Felmingham, Phuong, Chee, & Bryant, 2012). In addition to this, effects of blood glucose (released from the liver when cortisol levels are increased) on the EEM have also been investigated. Blake, Varnhagen, and Parent (2001) presented emotionally arousing and neutral stimuli to participants whilst recording their blood glucose. A positive correlation was found between participant's ratings of arousal and their blood glucose, and between blood glucose and subsequent emotional memory. Furthermore – and in relation to EEM specifically – fMRI research indicates that glucose administration significantly increased functional connectivity between the amygdala and hippocampus – a connection of known importance for the EEM effect (Parent et al., 2011). However, it is notable that research linking blood glucose and emotional memory has produced conflicting results, with some studies finding no effect of glucose (Brandt, Sünram-Lea, & Qualtrough, 2006; Ford, Scholey, Ayre, & Wesnes, 2002; for review see Messier, 2004).

One crucial limitation in the modulation model explanation of the EEM effect is that the processes involved (e.g. action of elevated levels of stress hormones in the brain) take an appreciable time to become effective, manifesting in observable EEM. Contrary to findings of neuro-behavioural investigations at short encoding-testing delays (<30 minutes; e.g. Ellis & Kesner, 1983), several studies find that emotional material is better recalled compared to neutral material at this latency (Bradley et al.,

1992; Hamann, Ely, Grafton, & Kilts, 1999; Putman, Van Honk, Kessels, Mulder, & Koppeschaar, 2004; Ritchey, Dolcos, & Cabeza, 2008; Tabert et al., 2001; Palomba, Angrilli, & Mini, 1997). For example in Study 1 of Bradley et al. (1992), participants were instructed to rate negative, positive and neutral pictures for arousal and valence using the Self-Assessment Manikin scale (SAM scale; Bradley & Lang, 1994) as a means of incidental encoding. Immediately following this, an unexpected free recall test ensued, in which it was found that highly arousing items (both positive and negative) were better recalled compared to neutral and low arousing items. Furthermore, it appears that the amygdala is not always required for EEM. Although a positive correlation has been found between amygdala activity at encoding and subsequent memory one month post-encoding, EEM captured 10 minutes post-encoding was evident without this correlation (Hamann et al., 1999). Moreover, research demonstrates that amygdala-lesioned patients still exhibit immediate EEM (LaBar & Phelps, 1998) suggesting the possible existence of an alternative or dual route to EEM, not currently explained by the modulation model. Hamann (2001) also highlights the conflict between long acting NE effects (lasting several minutes and at least remaining elevated during presentation of neutral stimuli in mixed list contexts) and the selective enhancement of emotional stimuli. If elevated NE alone were sufficient to improve memory, then this effect should not discriminate between emotional and neutral stimuli; because persistent elevated NE would act indiscriminately to improve memory for all stimuli.

To summarise, the modulation model has a wealth of robust support from a variety of studies, and explains EEM after a delay extremely well. However, evidence suggests that amygdala effects alone may not be sufficient to cause the EEM effect, and consolidation may not be the sole process upon which EEM is dependent.

The following section highlights the success of human neuroimaging research in delineating the neural EEM effect; outlining the common neural characteristics of this effect which will be pertinent in the current research.

1.3. Neuroimaging of the EEM effect

Before one can investigate the effect of manipulating the composition of an encoding list (“list-type” manipulation: mixed lists of emotional and neutral stimuli, versus pure lists of only emotional or only neutral stimuli) upon the neural correlates of the EEM effect, one must first understand the relevant literature explaining EEM effects in the neuroimaging modalities relevant to the current investigations. As the current body of work will employ EEG (electroencephalography) and fMRI (functional magnetic resonance imaging), EEM research in these modalities are reviewed below. In particular, because the current experiments will scan exclusively at encoding, only studies using the subsequent memory paradigm will be reviewed (Paller & Wagner, 2002). In these paradigms neural responses at encoding are sorted post-hoc into ‘remembered’ or ‘forgotten’ trials following the participant’s performance at retrieval. The differential of memory (Dm) may then be calculated by subtracting the neural correlates of forgotten events from the neural correlates of remembered events (Paller, Kutas, & Mayes, 1987); and is said to represent the neural activity predictive of successful memory (see Chapter 2 – General Methodology for more information).

1.3.1. Electroencephalography: The P300 and Late Positive Potential (LPP)

In EEG results a significant Dm effect is characterised by a larger amplitude positive-going event-related potential (ERP) for remembered items compared to that of forgotten items. This effect is commonly found at mid-line frontal, central and parietal scalp sites (e.g. Fz, Cz, Pz) at latencies after 300ms post-stimulus, which have been specified as effects of the P300 component, and/or the late positive potential (LPP) component. The P300 component is characterised as a positive-going voltage deflection beginning around 300ms post-stimulus (approximately 250-500ms) comprised of the P3a and P3b sub-components, which are thought to represent attention (particularly to novelty, a stimulus-driven component) and memory processes respectively (Polich, 2007). The LPP is characterised by a sustained positive deflection in the ERP extending over many milliseconds (ms) e.g. from 300-1500ms, and sometimes for the duration of stimulus presentation. The LPP is also associated with slow-wave (SW) components that emerge >500ms post-stimulus, and are said to be elicited when stimuli are subject to top-down processing (Olofsson, Nordin, Sequeira, & Polich, 2008).

For example, a Dm of this morphology was identified by Friedman and Trott, (2000) who used EEG to highlight the electrophysiological correlates of successful encoding using an immediate 'remember / know' recognition memory test. Supporting the finding first discovered by Sanquist, Rohrbaugh, Syndulko, and Lindsley (1980) their results indicated that 'remembered' items correlated with a more positive-going ERP waveform than did forgotten items. This effect was evident from ~300ms post-stimulus in frontal, central, and parietal scalp sites, a result that is well-replicated (Fabiani & Donchin, 1995; Gutchess, Ieui, & Federmeier, 2007;

Kaestner & Polich, 2011; Karis, Fabiani, & Donchin, 1984; Palomba, Angrilli, & Mini, 1997; Polich, 2007; Weinberg & Hajcak, 2010; Weymar et al., 2009). In relation to emotional memory specifically, studies have successfully identified electrophysiological correlates of the EEM in the P300 and LPP components.

Of crucial importance to the current work, Dolcos and Cabeza (2002) were the first to investigate the immediate EEM effect for emotional and neutral scenes using EEG methods. EEG data was recorded whilst participants viewed emotional and neutral stimuli selected from IAPS, (Lang, Bradley, & Cuthbert, 1997; 2008) which participants were instructed to remember for a later memory test. Immediately after each encoding stage a free recall test ensued. ERPs were split into early and late epochs, and analysis compared effects at frontal, central and parietal electrodes. The subsequent memory effect (recalled items more positive-going than forgotten items) was evident at a latency of 400 – 800ms post-stimulus. When analysing emotional and neutral items separately, further statistical tests revealed a significant subsequent memory effect for emotional stimuli at both early (400-600ms) and late (600-800ms) epochs, whereas the subsequent memory effect for neutral items was only apparent in the late epoch. Consequently the authors concluded that the success of encoding for emotional pictures utilised the same mechanism as for neutral pictures; but that emotional pictures are processed quicker than neutral pictures, which they propose demonstrates privileged access to mnemonic resources. These effects have been replicated many times, for example Weymar et al., (2009) found that during a late epoch (500-800ms) the Dm effect was significantly modulated by emotion in centro-parietal sites using emotional and neutral scenes (although the interpretation of these findings is somewhat different due to the delayed test used – 1 week later). In another study this emotion x memory interaction was also evident at

encoding in an earlier epoch (350-600ms) using an immediate recognition test of emotional and neutral faces (Righi et al., 2012).

This evidence and that of others (Gasbarri et al., 2006; Kiefer, Schuch, Schenck, & Fiedler, 2007; Schupp et al., 2000; Treese, Johansson, & Lindgren, 2010; Versace, Bradley, & Lang, 2010; Watts et al., 2014) shows the breadth- and success of electrophysiological research into the EEM, and provides useful information regarding target components – the P300 and LPP – to which a modulation by list-type (and associated distinctiveness processing) can be investigated.

1.3.2. Functional MRI

Functional MRI has also enjoyed success in delineating neural correlates of the EEM. In addition to regions predicted by the modulation model, fMRI research has also localised neural correlates of the immediate EEM effect to the prefrontal cortex (PFC), in particular the left ventrolateral and dorsolateral PFC (Dolcos, LaBar, & Cabeza, 2004); suggesting an extended network of brain regions beyond that of the amygdala and medial temporal lobe (MTL) structures, which may help to explain the behavioural findings of cognitive influences on EEM. Consistent with these findings Balconi and Ferrari (2012) administered rTMS (repeated transcranial magnetic stimulation) to the left dorsolateral PFC during an immediate recognition test of previously encoded emotional or neutral words. This was found to improve recognition and discrimination for emotional words (in this case positively valenced) compared to neutral, once again demonstrating the importance of the dlPFC in emotional memory – although this time at retrieval.

Transcending the implicit limitations of individual studies, literature reviews and quantitative meta-analyses have also been useful in explaining the neural EEM effect (LaBar & Cabeza, 2006; Murty, Ritchey, Adcock, & LaBar, 2011). LaBar and Cabeza's (2006) extensive review of the literature encompasses an overview of the emotional memory effects at encoding and retrieval, and considers evidence from lesion studies and evidence regarding fear conditioning. Their appraisal of the neuroimaging studies of emotional memory encoding highlights the importance of several regions: Unsurprisingly the AMY and MTL were considered markers of successful emotional encoding, and the functional connectivity of these regions was also noted of significance (e.g. after a delayed test of 3 weeks, Cahill et al., 1996). Activity of the prefrontal cortex (PFC) was also determined important, and differential valence / arousal was noted as a contributor to these effects (Dolcos, LaBar, et al., 2004; Kensinger & Corkin, 2004; both immediate EEM effects). This review asserts a lateralisation of AMY activation by gender (e.g. Canli, Desmond, Zhao, & Gabrieli, 2002), and a functional dissociation of the hippocampus (HPC) along the anterior-posterior axis (e.g. Dolcos, Labar, & Cabeza, 2004). Although providing a comprehensive review of the literature of the time, a quantitative meta-analytic approach provides more specificity and reliability in the conclusions made.

Murty et al. (2010) provided such a review using the activation likelihood estimation (ALE) approach (Laird et al., 2005). Activation co-ordinates from studies that reported regions associated with significantly greater activation for successful emotional compared to neutral memory were entered into the analysis; allowing a full brain voxel-wise analysis to determine the likelihood that a particular voxel would be activated in this contrast across studies. This analysis revealed reliable activations across studies in MTL regions (bilateral AMY, anterior hippocampus

[HPC], and parahippocampus [PHC]), in addition to regions in the middle temporal gyrus, middle occipital gyrus, middle frontal gyrus (MFG), inferior frontal gyrus (IFG), fusiform gyrus, supramarginal gyrus (SMG), claustrum, and caudate. Such a meta-analytic approach conveys greater statistical power over that of individual studies, and greater specificity compared to a qualitative review, and therefore it is reasonable to predict such activations in the current research. However, it should be noted that this meta-analysis included studies from only 15 experiments; and therefore a larger-scale meta-analysis may yield greater specificity yet. It is also of note that the methodology of emotional memory paradigms varies greatly; for example due to the varieties of ways in which emotion can be operationalised, the stimuli used (words, pictorial stimuli), how memory can be measured (recognition, free recall), and when memory is tested (short or long encoding-test delays, e.g. see Mickley Steinmetz, Schmidt, Zucker, & Kensinger, 2012). As such, activations specific to one or more of these parameters may be lost in such a meta-analysis; which may be of importance to the current study which utilises the lesser-used memory test of immediate free recall.

1.4. The EEM effect before consolidation: Cognitive effects.

An alternative suggestion to the modulation model (McGaugh, 2004) proposes that cognitive factors at encoding and retrieval influence the immediate EEM (mediation theory, Talmi, 2013). This theory particularly focuses on the effects of attention, semantic relatedness, and distinctiveness processing as contributors to the EEM effect. The summary that follows describes key empirical studies by Talmi and colleagues which informed mediation theory. Crucially, this summary also goes

beyond this literature, exploring other evidence which may explain the influence of cognitive processes on the EEM effect.

1.4.1. Attention

Although intuition may suggest that when we pay more attention to information / events that this in turn aids memory performance, a scientific understanding of the interplay between attention and memory is still developing (Chun & Johnson, 2011). Combining these two vast literatures is a task of considerable proportions, but empirical evidence does tend to agree with intuition (Eger, Henson, Driver, & Dolan, 2004; Uncapher, Hutchinson, & Wagner, 2011; Vuilleumier, 2005). However, when we narrow our line of enquiry to that of *emotional* memory specifically, evidence regarding the role of attention tells a mixed story. Research has investigated whether emotional stimuli garner more attention; and if so, whether the degree of attention to emotional items can mediate memory for the same. Mediation theory cites extra attention as a contributor to the EEM effect (evidence reviewed below), but beyond this the current thesis examines whether the *quality* of the attention attributed to a stimulus may also be important, and as such a review of both literatures follow.

Talmi, Schimmack, Paterson, & Moscovitch (2007) studied the relationship between emotion, attention, and memory using an auditory divided attention (DA) paradigm testing memory for emotionally positive, negative, and neutral scenes. Their DA reaction time (RT) data demonstrated that emotional stimuli involuntarily captured more attention than did neutral items (e.g. consistent with MacKay et al., 2004; Schimmack, 2005; Schmidt & Saari, 2007). Furthermore, mediator analysis showed that attention did indeed mediate the relationship between emotional

arousal and memory, and that this mediation varied according to valence: In positive stimuli this mediation explained the effect of emotion on memory completely; however this was not the case for negative stimuli, which only exerted a direct influence on memory. These results suggest that although attention may influence the EEM, it is not the sole factor. However, other evidence suggests that the modality of the DA task may be important. When the DA task taxes the same perceptual system as the experimental task, (i.e. using a visual DA task when testing memory of visual information) mediation analysis suggests that attention *does* significantly mediate emotional memory (Pottage & Schaefer, 2012); although the degree to which this occurs and whether other factors contribute is not clear.

Conversely, competing evidence suggests that emotional items do not always garner more attention compared to neutral; and that despite equivalent attention, emotional items are still better recalled. These claims are supported by evidence from Experiment 2 of Talmi et al., (2007), which found that although negative emotional and neutral pictures received the same amount of attention, emotional pictures were still better remembered. Similarly, Mickley Steinmetz & Kensinger (2013) who used eye tracking during encoding to measure attention, found that although scenes containing emotional items were better remembered compared to neutral items, there was no significant difference in the time fixated on emotional compared to neutral items; suggesting that attention did not mediate memory. Consistent with this, memory for the central detail of an emotional scene was significantly greater than that of non-emotional scenes, even when the experimenters compared only trials with equal numbers of emotional versus neutral eye fixations (Christianson, Loftus, Hoffman, & Loftus, 1991). Although bordering on a philosophical debate outside of the scope of this introduction, neural measures of *perception* (e.g. neural

activity in sensory perception brain regions) – which are arguably directly related to attention – do appear to co-vary more reliably with emotional stimuli and subsequent emotional memory (Markovic, Anderson, & Todd, 2014; Todd, Talmi, Schmitz, Susskind, & Anderson, 2012).

Together this research suggests that the amount of attention may not be important in explaining the EEM under ‘real world’ conditions because emotional stimuli do not always receive more attention; and because when attention to emotional and neutral stimuli is equivalent (naturally, or by trial matching procedures), the EEM is not abolished. However, when differential attentional allocation to emotional and neutral stimuli occurs (e.g. when DA conditions result in this outcome, or when the attentional measure is neural) attention does appear to mediate memory, although this seems to be valence and DA task dependent. Experimentally this implies that when a paradigm allows participants to attend naturally to emotional and neutral stimuli, that attention may not have a significant influence on the EEM.

Beyond potential differences in the *amount* of attention afforded to emotional and neutral stimuli, one could also consider the potential differences in the *quality* of attention paid to different stimuli. By quality of attention, we refer to the different types of attentional process, which may influence the EEM effect by different means. The following summary includes a review of the literature relevant to top-down and bottom-up attention, and neuroscientific literature on the dorsal (DAN) and ventral attentional networks (VAN) that respectively represent these types of attentional process in the brain.

In conditions outside of the laboratory, attention may be thought of as a fluid resource that can be easily allocated and re-allocated at will. For example, one may

choose to attend to a magazine article of interest, and this process is said to be governed by top-down attention, or endogenous intentional goal-directed attention. In this sense, information flows from higher order cognitive processing regions, to lower order perceptual processing regions in the brain. Conversely, if one should suddenly hear a loud crash whilst reading a magazine, attention may be involuntarily shifted to the sudden noise. This process is said to be driven by bottom-up attention, or exogenous stimulus-driven attention; where the flow of information is from lower order perceptual processing regions to higher order cognitive processing regions (Corbetta & Shulman, 2002). Empirical data from visual search and attentional capture tasks provide supporting evidence of these two distinct kinds of attention processes (Pinto, van der Leij, Sligte, Lamme, & Scholte, 2013). For example, in the visual search paradigm participants are instructed to direct their attention in a specific manner, e.g. to a specific location, or to a designated target stimulus; and the effect of this top-down attention is measured in terms of reaction time, accuracy of target detection, or neural measures such as fMRI BOLD (blood oxygenation level dependent) activity in the brain. Typically, engagement of top-down processing (e.g. induced by cueing) led to quicker target identification (e.g. Bressler, Tang, Sylvester, Shulman, & Corbetta, 2008; Giesbrecht, Woldorff, Song, & Mangun, 2003). However, stimuli may also involuntarily 'grab' attention when they are unexpected, distinct, or salient. For example Schreij, Owens and Theeuwes (2008) presented multiple trials of a cued visual search to participants, and in 50% of trials an additional object (an abrupt onset of a new target location and a novel character within it) was also present. Even though participants were told to expect these abrupt onsets, and were reliably informed that the target would never be found in the additional abrupt onset object; reaction times were still significantly slower for abrupt onset trials than for

standard trials. This was true even when the target and abrupt onset object were completely different (i.e. the target and distracter were different colours and different characters). The authors interpret these findings by concluding that attention to the abrupt onset object was entirely exogenous, and that this attention detracted from sustained top-down processing of an intentionally applied search strategy, as shown by slower RTs for target detection.

A wealth of research has investigated these different qualities of attention, in particular neuroscientific investigation has clearly delineated two dissociable yet interacting networks: the ventral attention network (VAN; bottom-up) and dorsal attention network (DAN; top-down). Corbetta and Shulman (2002) were among the first to dissociate the neural processes associated with top-down and bottom-up processing. In their extensive review of neuroscientific investigation into attentional control, they propose that a predominantly right lateralised ventral frontoparietal network (VAN) including the temporal parietal junction (TPJ), inferior frontal gyrus (IFG), and ventral prefrontal cortex (PFC); acts to detect (features of) stimuli that are highly behaviourally salient, despite often being task irrelevant. Importantly, Corbetta and Shulman proposed that this network could act as a circuit breaker to ongoing top-down processing which is said to be governed by a dorsal frontoparietal network (DAN) involving the intraparietal sulcus (IPS), frontal eye field (FEF), and middle temporal complex (MT+). This neural distinction between these two types of attentional network has received overwhelming support in the literature (Carrasco, 2011; Fox, Corbetta, Snyder, Vincent, & Raichle, 2006; Humphreys & Lambon Ralph, 2014; Kaspar, 2013; Katsuki & Constantinidis, 2014; Shulman et al., 2003; Vossel, Geng, & Fink, 2014).

Moreover, these two networks have also been linked extensively to encoding success and failure; with activations in the DAN relating to successful subsequent memory, and activations in the VAN commonly relating to subsequent memory failure (Shulman, Astafiev, McAvoy, d'Avossa, & Corbetta, 2007; Uncapher et al., 2011; Uncapher & Wagner, 2009). That VAN activity positively correlates with memory failure is not surprising given its known role in attentional reorienting to *behaviourally* relevant, but often *task-irrelevant* stimuli (which are often distractors). However, the extant findings do not preclude an opposite effect: positive correlation between VAN activity and memory *success*; if a behaviourally relevant stimulus (e.g. a picture of a crying child) was also the target for subsequent memory, for example in an emotional memory paradigm (Murty et al., 2010; Viviani, 2013; Vuilleumier, 2005).

Bottom-up reflexive attention is said to be attracted by stimuli which are novel, salient, and/or convey a personal significance to the perceiver (Cowan, 1995). In relation to the EEM it is plausible that emotional stimuli may fit both of these descriptions: Emotional stimuli may be novel relative to neutral stimuli due to secondary distinctiveness (i.e. are not commonly encountered; Schmidt, 1991); and are of significance because they convey information that may potentially be important for the perceiver's survival (i.e. assessment of threat). It may therefore be reasoned that preferential bottom-up attention to emotional stimuli increase the memorability of these items; and this may be especially so in mixed list conditions, where emotional stimuli also convey a primary distinctiveness (relative to neutral items in the list; Schmidt, 1991). In pure list encoding conditions containing only emotional items, presumably one would not need to reflexively reorient to each subsequent emotional stimulus, as all stimuli convey the same properties of arousal and valence, and

therefore a more uniform processing may be engaged (perhaps employing a top-down strategy, after the initial reorienting).

Given this brief review, it is clear to see how the *quality* of attention may play a significant role in the EEM beyond the quantity of attention, which has been the focus of previous research. Research on attention suggests that emotional items should reflexively capture attentional resources, especially in mixed lists where the intermixing of emotional and neutral stimuli increase the relative salience and novelty of emotional stimuli.

1.4.2. Semantic relatedness

Mediation theory also cites semantic relatedness as a significant contributor to the EEM effect (Talmi, 2013). To be specific, mediation theory thus far has investigated semantic relatedness as a property of the presented stimuli, not semantic *processing* (as distinguished in Section 1.1.3 above); although it is implied that one may correlate with another – i.e. stimuli that share a semantic relatedness link may have a greater likelihood of receiving semantic processing.

Semantic relatedness is often investigated in experiments using words as stimuli (e.g. Buchanan, Westbury, & Burgess, 2001; Landauer & Foltz, 1998; Nelson, Kitto, Galea, McEvoy, & Bruza, 2013) however emerging research using pictorial stimuli now abounds. Standard negatively valenced *emotional* pictorial stimuli (E.g. the international affective picture system [IAPS] Lang, Bradley, & Cuthbert, 1997; 2008) are noted to have higher levels of semantic relatedness compared to neutral stimuli because they are more likely to share a thematic connection (e.g. scenes of war, poverty, and torture); whereas thematic connections between neutral stimuli

(e.g. scenes of the countryside, a hammer, and a secretary at work) are more disparate (Talmi et al., 2007). This inherent differential semantic relatedness between emotional and neutral items is said to contribute to the EEM effect. Indeed many studies (partly) attribute the EEM effect to differential semantic relatedness without directly manipulating this factor (Kalpouzos, Fischer, Rieckmann, MacDonald, & Bäckman, 2012; Maratos, Allan, & Rugg, 2000; Siddiqui & Unsworth, 2011; Verde, Stone, Hatch, & Schnall, 2010; Wang & Fu, 2011). Direct empirical evidence attesting to the contribution of valence-differential semantic relatedness to the EEM effect is now well-established (Balconi & Ferrari, 2012; Buchanan, Etzel, Adolphs, & Tranel, 2006; Talmi, Luk, McGarry, & Moscovitch, 2007; Talmi, Schimmack, et al., 2007; Talmi & McGarry, 2012). At encoding for example, under DA conditions the EEM effect was significantly larger when testing memory for mixed lists of emotional and random-neutral pictures (low/no semantic relatedness of neutral stimuli), compared to when testing memory for mixed lists of emotional and *related*-neutral pictures (Talmi & McGarry, 2012; Talmi, Schimmack, et al., 2007). However, when emotional and related-neutral stimuli were ordered as blocks within a mixed list (e.g. first half of encoding trials emotional, second half of trials related-neutral, presented as one encoding list) the EEM was present despite controlling for semantic relatedness of the neutral stimuli (Experiment 2, Schmidt & Saari, 2007). This replicates previous work of D'Agostino (1969) who found better memory of non-emotional categorised words in blocked compared to random presentation encoding lists. This suggests that the organisation of the encoding list according to a semantic category (i.e. contiguously presented emotional and neutral stimuli) is also important, and suggests that list organisation may interact with semantic relatedness effects.

A pertinent body of research which is also concerned with the categorisation of stimuli according to semantic relatedness is that of schema research. Bartlett (1932) refers to schema as, “an active integration of past reactions, or of past experiences...”, although it may be thought of more simply as any overarching meaning, knowledge or information that connects two or more items/events. Schemas are formed when one processes information about the world over time, and represent meaningful categories of information. Schema research suggests that schema-congruent information is well remembered (van Buuren et al., 2014; van Kesteren, Rijpkema, Ruiter, & Fernández, 2013; for reviews see Alba & Hasher, 1983; and Ghosh & Gilboa, 2014); although memory of schema-incongruent information may also be high. Neuroscientific research has helped to clarify this issue: According to the SLIMM model (schema-linked interactions between medial prefrontal and medial temporal regions; van Kesteren, Ruiter, Fernández, & Henson, 2012), schema congruent items (e.g. a rubber duck in a bathtub) are processed by the medial prefrontal cortex (mPFC) and areas of the stored schema representation in the neocortex; whereas schema incongruent information (e.g. rubber duck in a bank) is processed by the medial temporal lobe (MTL) where a new representation is formed. If information is neither congruent nor incongruent then both the mPFC and MTL process the information weakly, leading to poorer encoding (building upon van Kesteren, Rijpkema, Ruiter, & Fernández, 2010; van Kesteren, Fernández, Norris, & Hermans, 2010). If it holds that a schema is underpinned by some shared semantic relatedness amongst items, then this model may also prove a useful explanation of the semantic relatedness contributions to the EEM.

Semantic relatedness has also been cited as a factor which contributes to the EEM at *retrieval*; and is said to interact with other factors such as context and

temporal contiguity (Polyn, Norman, & Kahana, 2009a, 2009b). The influence of semantic relatedness has been evidenced by investigating clustering effects during free recall: Stimuli that represent distinct thematic groups with high within-set semantic relatedness (e.g. clothing items versus utensil items) are presented in a random order to participants. At retrieval, the extent to which participants consecutively recall items from the same semantic category (“clustering”) may then be calculated (e.g. using the List Based Semantic Clustering Index [LBC_{sem}]; Stricker, Brown, Wixted, Baldo, & Delis, 2002). It is found that when participants make use of category information at recall, that this significantly improves memory performance (Tulving, 1962). This has also been evidenced when the categories are defined by valence. For example Talmi, Luk, et al., (2007) sorted participants as those who had high or low clustering scores based on their free recall of emotional and related-neutral pictures. It was found that participants with a tendency against clustering had overall lower memory compared to participants with a tendency towards clustering; and that only these low cluster-score participants demonstrated an EEM effect (no difference in memory performance of emotional and neutral stimuli for high cluster participants). One plausible explanation of this finding is that making use of semantic relatedness information at retrieval may confer a mnemonic benefit for neutral stimuli, thus equating memory to that of emotional stimuli and abolishing the EEM effect.

In summary, research suggests that differential semantic relatedness between encoded items significantly contributes to the EEM; and that when semantic relatedness is utilised at retrieval, this can ‘protect’ against the EEM effect. This evidence positions semantic relatedness as an important factor in any research investigating the EEM.

One plausible limitation to mediation theory (Talmi, 2013) is that the relationship between controlling semantic relatedness and an equivalence of emotional and neutral memory has been used to imply that an associated cognitive process has also been equated (e.g. semantic processing, or semantic relatedness processing). Although controlling for between-set differential semantic relatedness effectively eliminates an important confound in the emotional memory paradigm, it is a stretch to associate this with an equivalence of cognitive processing. Therefore it is possible that differential semantic processing of emotional and neutral stimuli still contribute to the EEM effect despite this stimulus property being controlled. In order to best address this query, neuroimaging data will be examined for evidence of differential semantic processing at encoding, for example in known semantic processing areas such as the anterior temporal lobes (ATLs; Skipper, Ross, & Olson, 2011; Visser, Jefferies, & Lambon Ralph, 2010; Zahn et al., 2007).

1.4.3. Distinctiveness processing

Mediation theory also cites distinctiveness processing as a significant contributor to the EEM effect, as evoked in encoding lists of mixed emotional and neutral stimuli. Research shows that when stimuli are controlled for semantic relatedness; 'pure' lists containing either only emotional or only neutral stimuli are recalled equally well. However, when a mixed list of stimuli contains both emotional and neutral stimuli, the neutral stimuli are remembered less well compared to the emotional stimuli in the same mixed list, or compared to neutral items presented in pure neutral lists (Buchanan et al., 2006; Schmidt & Saari, 2007; Talmi, Schimmack, et al., 2007). Given that semantic relatedness and attention were controlled in these experiments, the

crucial difference between these stimuli is the list composition (list type) – from which the authors propose that the associated cognitive process is distinctiveness processing (although the mechanism underlying distinctiveness processing is not further elucidated).

The further elucidation of the mechanism of distinctiveness processing as it contributes to the EEM is a central aim of this body of work. Without a better characterisation of how this process contributes to the EEM effect, all that can be asserted is a *description* of the effects of intermixing emotional and neutral stimuli; whereas it is of greater importance to provide a working *explanation* of these effects. Indeed, it is acknowledged that definitions of distinctiveness per se, and distinctiveness processing are lacking, and have failed to detail the mechanism that underlies mnemonic benefit (Schmidt, 1991). Current explanations of distinctiveness processing built upon the work of Schmidt (1991), and Hunt and McDaniel (1993) have provided much useful evidence in defining distinctiveness and distinctiveness processing. However, whether these definitions apply when emotion is the category identifier (i.e. categories of emotional and neutral stimuli, compared to other distinctiveness processing research, e.g. which used orthography or colour as category identifiers) remains to be confirmed; although see evidence from Williams, Mathews and MacLeod (1996) which outlines effects consistent with distinctiveness processing in an emotional Stroop task in patient populations. Indeed, in Schmidt's (1991) paper outlining the challenges faced when defining distinctiveness, emotion is separated as a special case of category identification.

The summary that follows outlines research which investigated distinctiveness and distinctiveness processing, using non-emotional category identifiers (such as orthography, word colour, stimulus frequency etc.); and an

alternative literature from the field of neuroscience that offers plausible accounts of mixed-list EEM effects, which may also serve to elucidate a distinctiveness processing mechanism.

A key feature of distinctiveness processing as we define it, is that it is a sustained cognitive process, i.e. lasting throughout the entirety of a mixed-list encoding episode. However, early distinctiveness processing research based on the isolation effect (von Restorff, 1933) assumed that the effect of distinctiveness (to improve memory) was not manifest during encoding, more likely at consolidation or retrieval. This is because it was found that memory for distinctive items occupying the first position in a list (before it could be deemed distinctive relative to other-list items) was greater than non-distinct first position items (items which subsequently conformed to a list theme). von Restorff concluded that participants could not have processed such first position items as distinctive (i.e. before a list context had been established), and this led to the conclusion that distinctiveness processing must have occurred after the event, i.e. at consolidation or retrieval. However, this interpretation assumes that distinctiveness processing is a linear process occurring in a strict temporal order from stimulus-to-stimulus; whereas if one relaxes this assumption - allowing distinctiveness processing to act in a feed-forward and feedback manner throughout an encoding list, it is possible to conceive how distinctiveness processing could have caused this effect. This would at least implicate working memory as a necessary parallel process (or sub-process) of distinctiveness processing, because some items of the list would need to be held in working memory and updated as more information became apparent with subsequent stimuli. This in turn could inform the participant about the context of the list, and the distinctive nature of the first item. However, distinctiveness processing has never been

characterised in terms of the associated cognitive contributors such as working memory, and therefore further evidence is needed to support this claim.

Based on more recent evidence, Hunt and McDaniel (1993) state that distinctiveness processing is achieved by two sub-processes: item-specific and relational processing; and that this combination of processing produces optimal memory, over and above either process carried out singularly. Indeed empirical evidence supports this claim: Research by Epstein, Phillips, and Johnson (1975) using similarity and difference judgements as proxies for item-specific and relational processing showed that optimal memory performance was found for semantically related words for which difference-judgements were made, and semantically unrelated words for which similarity-judgements were made. Moreover, research shows that when both relational and item-specific processing are employed, this is more beneficial to memory than either process carried out twice (Einstein & Hunt, 1980). Similarly, Hunt and Einstein (1981) found that relational processing did not increase memory for already obviously related items ('typical' items) whereas this type of processing did increase memory for items which had less obvious category membership ('atypical' items). Conversely, the item-specific task improved memory only for typical items, suggesting that category membership (which may be a semantic relationship) must be already apparent in order for extra item processing to become beneficial.

However, as previously stated, relational and item-specific processing may not underlie distinctiveness processing as it applies to emotional stimuli. We speculate that neuroscientific models explaining the mixed-list EEM effect may inadvertently hold clues as to how best to characterise distinctiveness processing in mixed list circumstances. For example, binding theory (Hadley & MacKay, 2006) states that

item-context associations contribute to successful memory, and that processing capacity to form these links is limited. In mixed lists, emotional items are said to dominate this process which binds a stimulus to its context, improving memory relative to neutral items in mixed lists but not in pure lists (where no competition for this resource exists). Given that both binding theory and distinctiveness processing can potentially explain mixed-list EEM effects, it is possible to conceive of item-context binding as a feature of distinctiveness processing. However it is equally plausible to propose that distinctiveness processing may be a constituent process of binding theory. That is to speculate that in perceiving the differences in valence (and/or arousal) of the emotional and neutral stimuli in mixed lists – i.e. using distinctiveness processing – stimuli may hence compete for binding resources. Furthermore, presumably after item-context binding has occurred preferentially for the emotional items (e.g. which may represent 50% of the encoding items in a given mixed list), these items then share a similarity in their binding to the same context, and possess a difference to those items not bound (or less-well bound) to the context – which may again be facilitated by distinctiveness processing (perceiving differential item-context binding).

Representing a competing model, the list-type dependent EEM has also been explained in terms of Arousal-Biased Competition theory (Lee, Itti, & Mather, 2012; Mather & Sutherland, 2011; Sutherland & Mather, 2012). In ABC theory, experiencing arousal acts to increase the *competition* between items for memory-supporting resources such as attention. The memorial outcome of this state of competition induced by arousal is determined by the prioritisation of each to be remembered item, which is said to be dependent on top-down and bottom up processing, emotion, and social relevance. This theory was tested (Sutherland & Mather, 2012) by exposing

participants to arousing / non-arousing sounds, followed by the presentation of several letters to be remembered (some with a darker, more prominent colour). Those participants who listened to arousing sounds remembered more dark letters than light; and more dark letters than those participants who heard non-arousing sounds. Although this experiment used an initial arousing cue to induce arousal-biased competition, Mather and Sutherland acknowledge that in other circumstances this competition for resources may be instigated by a stimulus itself (e.g. an emotional stimulus amongst neutral stimuli). ABC theory has been further defined in terms of a neuroscientific model (Glutamate Amplifies Noradrenergic Effects [GANE]; Mather, Clewett, Sakaki, & Harley, 2015), which states that brain regions that process stimuli of high priority necessitating high levels of glutamate, interact with arousal-dependent norepinephrine (NE) released by the locus coeruleus, creating 'hot spots' of NE activity. Crucially, this model explains how arousal (which leads to diffuse elevation of NE in the brain) can have a differential effect on high priority representations (e.g. neutral stimuli that are task relevant and therefore supported by increased glutamate) and low priority representations (e.g. when neutral stimuli or peripheral details are considered irrelevant, therefore are not associated with increased glutamate). Therefore, it is clear that distinctiveness processing as a psychological construct, and the ABC / GANE model approaches both seek to explain a common phenomenon: the mixed-list EEM effect. As such it would be pertinent to examine the data collected for evidence that supports these models.

Despite behavioural evidence of an EEM effect before consolidation as reviewed here, the neural correlates of this immediate EEM are not well understood. The neural correlates of cognitive factors (such as distinctiveness processing) as contributors to this effect are especially under-investigated considering the

behavioural evidence that attest to their importance (as outlined above). Taken together the existing literature illustrates a clear need for further investigation of the correlates of this immediate EEM effect and the cognitive contributions to it; which may be useful to portray a clearer, more holistic picture of the EEM, if synthesised with the modulation model.

1.5. Conclusion

The preceding review has provided definitions of emotion, memory and pertinent cognitive factors: semantic relatedness, and distinctiveness processing. Of significance for the definitions of these terms is the dissociation between objective stimulus properties (such as semantic relatedness and distinctiveness) and the processing of these stimulus qualities involving cognition: semantic processing and distinctiveness processing. This review has critically evaluated the modulation model (McGaugh, 2004), noting its limitation in explaining emotional memory only after consolidation which takes place over hours or days. An alternative explanation provided by mediation theory (Talmi, 2013) which explains the immediate EEM (before consolidation) in terms of extra cognitive resources afforded to emotional stimuli was also critically appraised. Notably, this theory is relatively lacking in neuroscientific evidence compared to that of the modulation model. Areas of extension to this work are noted: such as investigating the quality of attention rather quantity, and working towards a better definition of distinctiveness processing, as each contribute to the EEM. Crucially, gathering neuroimaging data at encoding will verify the existence of encoding-specific effects to the immediate EEM, whereas the

behavioural research to date cannot determine the temporal site of these investigated effects.

Therefore the current body of work seeks to better characterise the neural underpinnings of the cognitive contributions to the EEM effect, using behavioural and neuroimaging techniques. Whilst controlling the stimulus property semantic relatedness, the immediate memory of emotional and neutral pictorial scenes will be tested using free recall. This work will develop a larger stimulus set to enable EEM testing using neuroimaging techniques (which require a greater amount of trials due to poor signal to noise ratio); and use EEG and fMRI to delineate the temporal and spatial loci of cognitive contributions to the EEM effect. Finally, behavioural data will be gathered to test the importance of the constituents of distinctiveness processing: item-specific and relational processing, as they contribute to the EEM. This will enable a better classification of the term distinctiveness processing when referred to as a contributor to the EEM effect. Altogether this work will show if and how cognitive factors contribute to the immediate EEM, questions which cannot be answered by the prevalent modulation model.

2. General Methodology

2.1. Behavioural investigation of the emotional enhancement of memory

2.1.1. Paradigm overview

Chapters 4, 5, and 6 use the same basic free recall paradigm, which are adapted for the neuroimaging modality (EEG, fMRI) or encoding manipulation (behavioural experiment, chapter 6). All paradigms have three common elements: encoding list, distractor task, free recall – see Figure 2.1; also see individual chapters for specific details.

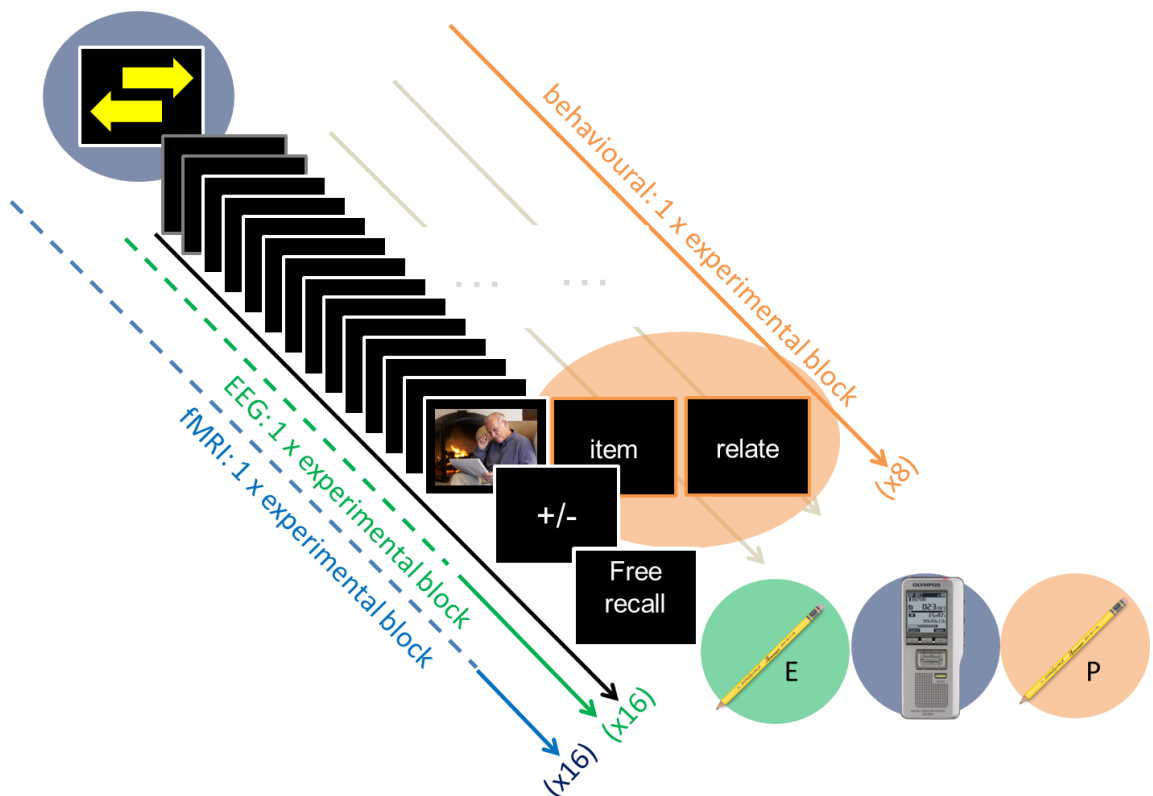


Figure 2.1. Schematic of the free recall paradigm and its adaptations

The standard paradigm (black arrow) begins with an encoding list of 2 buffer items (grey outline), and 12 experimental trials, each containing emotional or neutral pictorial stimuli (relative ratio of stimulus valence is according to list type: pure emotional, pure neutral, mixed). In the standard paradigm encoding was intentional

and passive. Participants then performed an arithmetic-based distractor task (“+/-”; 60s), followed by free recall (3mins). The method of recording free recall varied by experiment: For EEG (green) recall was spoken aloud by the participant and recorded by hand by the experimenter (E); for fMRI (blue) recall was spoken aloud by the participant and recorded via the scanner intercom using a Dictaphone; for the behavioural experiment, participants (P) wrote down their own free recall. For the fMRI study an additional task (“arrows”, blue circle) was implemented at the beginning of each block. For the behavioural experiment (orange), participants were placed into one of 3 conditions: passive encoding (as per the standard paradigm, so called ‘baseline’ condition), item-specific processing instructions (‘item’), or relational processing instructions (‘relate’). Arrows denote the length of one block (dashed line represents duration of scanning), and the number of blocks in each paradigm is displayed at the end of each arrow (also colour coded).

2.1.2. Using free recall to test memory

Many empirical studies favour the use of recognition memory over free recall for the test of pictorial memory due to its practicality: Responses of recognition can be coded computationally in real-time as ‘hits’ (remembered), ‘misses’ (forgotten), ‘false alarms’ and ‘correct rejections’. Conversely free recall requires the experimenter to check recall descriptions against the stimuli presented to determine the memory status of each item, which requires the time and expertise of the experimenter. Because of the constrained nature of recognition (usually answers are binary choices made by button press e.g. remember: yes/no; or item: old/new etc.) this also makes it easy to scan retrieval using neuroimaging techniques such as electroencephalography (EEG), or functional Magnetic Resonance Imaging (fMRI). Scanning during free recall is less practical due to the fact that a description of the recalled item is required, which necessitates movement (from speaking aloud or writing down recall) which creates artefacts during scanning. By the unconstrained nature of free recall, it is also impossible to determine what kinds of processes a person is engaging in whilst recalling, and at what time these processes begin / end. This is not the case for

recognition memory because recognition is time locked to an event – e.g. the presentation of the test stimulus, or the participants’ response. Despite these practical limitations on the scanning of retrieval, free recall remains an attractive option for the investigation of emotional memory for several reasons. A general but nonetheless important point is that researchers investigating emotional memory often wish to make some generalisation to emotional memory *per se*, outside of the experimental setting. In order to generalise to such ‘real-world’ experiences, free recall presents the best ecologically valid match to everyday remembering of events (i.e. it is spontaneous and unconstrained). Although ecological validity is often seen as a contrived evaluative statement, it is important in the investigation of human emotional memory for the success of bridging the gap between basic and clinical research. For example, research may be applied to therapeutic models and treatments of psychological disorders that are instantiated or maintained by emotional events, and/or intrusive memories, such as post-traumatic stress disorder (Ehlers & Clark, 2000; Lanius et al., 2003; Tapia, Clarys, Bugajska, & El-Hage, 2012). In addition to this, although studies of memory *per se* may favour other methods, a diverse range of studies testing *emotional memory* have used free recall as the preferred test of memory (Cahill et al., 1996; Dickerson et al., 2007; Dolcos & Cabeza, 2002; Felmingham et al., 2012; Fernández et al., 1998; Pottage & Schaefer, 2012; Siddiqui & Unsworth, 2011; Talmi, Luk, et al., 2007; Talmi & Moscovitch, 2004; Wolf, 2012); and it is furthermore suggested that this may indeed be the *optimal* method of testing emotional memory specifically (Dolan, 2002).

2.1.3. The subsequent memory paradigm and difference due to memory (Dm)

Many studies interested in encoding processes use the subsequent memory paradigm to investigate the neural correlates of encoding in the brain (Paller & Wagner, 2002). Enabled by the advancement of event-related designs in neuroimaging research, the subsequent memory paradigm involves sorting encoding trials post-hoc as 'remembered-' or 'forgotten-' trials based on performance at a later memory test. The neural activity associated with these events can then be contrasted [remembered – forgotten] to determine the 'Dm' – or difference due to memory (Paller, Kutas, & Mayes, 1987). The resultant activity of a Dm contrast can therefore be thought of as the activity over-and-above typical perceptual processing, and which is predictive of later successful memory – information not discernible from the blocked design experiments some years ago (Nyberg, 1998). These tools are therefore of crucial importance to the investigation of memory, and have been a mainstay of memory research in many neuroimaging modalities for many years (e.g. *using fMRI*: Brewer, Zhao, Desmond, Glover, & Gabrieli, 1998; *using EEG*: Sanquist, Rohrbaugh, Syndulko, & Lindsley, 1980; *for reviews see* Wagner, Koutstaal, & Schacter, 1999; Murty, Ritchey, Adcock, & Labar, 2010; Uncapher & Wagner, 2009).

It should be noted that the Dm effect is sensitive to a number of different experimental manipulations such as stimulus type, orienting task, and test of memory (for review see Wagner, Koutstaal, & Schacter, 1999). For example, evidence suggests that the Dm effect is most reliably induced when memory is probed using unintentional encoding and free recall at retrieval, (Paller, McCarthy, & Wood, 1988); with intentional encoding paradigms noted to produce Dm ERP effects with a more frontal topography (e.g. Friedman, 1990). Furthermore, although Dm effects for

pictorial stimuli have been reported (Dolcos & Cabeza, 2002); this appears to rely somewhat on the meaningfulness of the stimuli, as significant Dm effects were not reported for such stimuli as abstract line drawings and geometric symbols (e.g. Fox, Michie & Coltheart, 1990; Van Petten & Senkfor, 1996).

2.2. Neuroscientific investigation of the emotional enhancement of memory

2.2.1. Electroencephalography and event-related potentials

Electroencephalography (EEG, used in Chapter 4) is a non-invasive measure of the electrical activity of the brain as measured at the scalp. In brief, electrical currents in the brain generated by post-synaptic potentials (PSPs) within groups of similarly oriented pyramidal cells (found in layers III, V, and VI of the cortex) sum to create extracellular currents. PSPs effectively create electrical dipoles (like a battery with positively and negatively charged ends), which – when aligned together, oriented perpendicular to the scalp, and in sufficient number – form an equivalent current dipole; measureable at the scalp. The event-related potential (ERP) is the recording of this measurable signal at the scalp over time, as time-locked to specific events (e.g. experimental trials). This signal may be represented as topography maps – maps of equi-voltage across the scalp; or as ERP waveforms – the timecourse of electrical activity amplitude (voltage) at a particular location on the scalp, recorded by the electrodes. Importantly, EEG measures are almost always averaged over the given trials of a condition, and then are usually also averaged over participants too. This ensures a better signal to noise (SNR) ratio, meaning that any ‘unusual’ activity will be filtered out using these averaging procedures (Luck & Kappenman, 2012). Reliable

peaks of activation (positive or negative in polarity) are termed ERP components, which are said to represent psychological and neural processes. The presence or absence-, and amplitude/latency differences- of components can then be compared between conditions, allowing researchers to make inferences about mental processes of interest.

2.2.2. Functional Magnetic Resonance Imaging

Functional magnetic resonance imaging (fMRI, used in Chapter 5) is an alternative non-invasive measure of brain function, which typically uses the blood oxygen level dependent (BOLD) as a proxy measure of brain activity.

This is made possible by the nuclear magnetic resonance properties (NMR) of the nuclei of atoms. Nuclei with such NMR properties (i.e. a magnetic moment and an angular momentum) can be reliably manipulated by applying and perturbing a strong magnetic field (typically above 1.5 Tesla) using an MRI machine. Under such circumstances, the net magnetisation of groups of nuclei in a volume will align to the magnetic field, but their alignment can be rearranged (i.e. through the transverse plane) by applying a radiofrequency pulse generated by a magnetic resonance (MR) coil. The energy from the radiofrequency pulse is enough to change nuclei from a low- to high- energy state (“excitation”), and it is the return of these nuclei to an equilibrium state (“relaxation”, detected by the MR coil) that forms the basis of the MRI signal (Heuttel, Song & McCarthy 2009).

Measuring brain function based on the BOLD is predicated on the fact that active neuronal assemblies require metabolic resources supplied by the blood (for a detailed description of this process see Hall et al., 2014). Haemoglobin “carries”

oxygen in the blood, and is paramagnetic (has magnetic qualities) after the oxygen has been “used” (deoxygenated haemoglobin, dHb). This paramagnetic property distorts the magnetic field of the surrounding nuclei, preventing coherence amongst assemblies of nuclei, thus altering their relaxation rate (Thulborn, Waterton, Matthews, & Radda, 1982). Therefore, when neurons use oxygen in the blood the presence of dHb creates differential relaxation rates for active- compared to non-active regions of the brain. It is this differential relaxation based on the presence of dHb that allows the measurement of MR signal from the blood (BOLD). The reliance of the signal on the relatively slow (order of seconds) haemodynamic response in the brain affords fMRI a lower temporal resolution compared to that of EEG. However, the spatial resolution of this method is better than that of EEG – in the order of millimetres.

2.2.3. Statistical Parametric Mapping

In order to analyse neuroimaging data (both EEG and fMRI), statistical parametric modelling (SPM) may be used (current research employed SPM12, implemented in MATLAB; The MathWorks, Inc.). The scanned brain volume is divided into 3-dimensional units called ‘voxels’ which are usually $2\text{mm}^3 - 3\text{mm}^3$ (or 2-dimensional pixels for EEG, as described above), and a statistical test is carried out for each voxel (or pixel). The brain activity (Y) of each voxel (or pixel) is regressed with explanatory variables (X) to create beta values (β) which aim to optimally model the variance in the data, whilst minimising any residual error. These parameters (along with a constant ‘c’, and an error term ‘ ϵ ’) are held in the design matrix which models the data (see equation 1) and provides a platform to perform statistical tests.

$$Y = X\beta + c + \varepsilon \quad (\text{Eq. 1})$$

The statistical significance of an explanatory variable is determined by dividing the variance of that variable by the error term, and this forms the basis of the generalised linear model (GLM).

2.3. Neuroimaging model specification and evaluation

Although typical for the analysis of fMRI data, relatively fewer EEG studies analyse data using SPM (although see Litvak et al., 2012; Talmi, Atkinson, & El-Deredy, 2013; see Kiebel & Friston, 2004a, 2004b; Litvak et al., 2011 for methods). We chose this method of analysis over other possible EEG analyses (which usually average the extracted amplitude data from a-priori defined groups of electrodes for discrete time bins within the epoch of interest) for two reasons. Firstly, and generally speaking, congruency of analysis methods between the EEG and fMRI experiments was preferable given the fact that the same experimental paradigm was used for both experiments (although adapted, see above and specific chapters), and given the presentation of these two experiments as parts of the PhD thesis as a complete body of work. Secondly, and more specifically, analysing the EEG data using SPM represented a less constrained form of analysis. To be explicit – using SPM prevented the need for a-priori topographical- and latency-of-interest definitions, allowing for a whole brain analysis to be carried out; thus reducing confirmation bias and balancing the probability of type I and type II errors. Another advantage of using SPM for the pre-processing and analysis of this data was that the methodology was more

transparent; compared to BESA (brain electrical source analysis) for example, where we found that the algorithms behind the functions applied to the data were more difficult to obtain. Conversely, the transparency of the functions in SPM made it easier to adapt pre-processing and analysis steps, thus optimising the data and results for these specific paradigms. Using SPM to pre-process EEG data not only produces graphical ERP outputs; but 2 dimensional scalp images of 64 x 64 pixels (pixel dimension: space x time) are also created based on data interpolated from all scalp electrode activity. This is akin to the scans entered into a second level fMRI design.

Both EEG and fMRI second-level models employed flexible factorial designs which enabled the modelling of subject effects in an analysis similar to an ANOVA for behavioural data. The flexible factorial design was preferred (over a factorial design, or simple t-tests) for several reasons. Firstly, due to the nature of the questions we planned to ask of the data (i.e. main effects contrasts, and several interaction analyses) it would not have been practical to use simple t-contrasts as the model for results. We also preferred the flexible factorial over the factorial design because we specifically sought to model the subject factor. Modelling the subject factor was advantageous because it effectively reduced any participant-specific (idiosyncratic) variance, which would otherwise be noise in the model. Participant specific variance was likely because the encoding of items in both the EEG and fMRI paradigms was unconstrained – i.e. no specific instructions were given as to how to encode the stimuli other than not to use a specific strategy e.g. a loci strategy. Therefore, with no explicit orienting task or encoding instructions it is likely that encoding activity would vary somewhat between participants. Moreover, modelling the subject effects was particularly useful for the EEG experiment, where data was collected at several

different time-points throughout the PhD, which may have inadvertently added to subject-specific variance.

We adapted the code for the flexible factorial model to allow more than the customary 3 levels of design (usually subject + 2 other factors); to enable the modelling of the subject factor, plus the experimental factors: list-type (mixed vs. pure), valence (emotional vs. neutral), and memory (recalled vs. forgotten). This presented an advantage over using the memory contrast (Dm) as input at the second level (which would have fit the customary 3 factors of the flexible factorial design), because it allowed us to probe the amplitude- and direction- of effects more deeply if required (see Figure 2.2). As is indicated by Figure 2.2, removing the individual levels of the factor memory in favour of using a Dm contrast may inflate the probability of obtaining false negative results. For example, this may occur as a result of comparing two apparently equal Dm contrasts (i.e. no significant differences detected), but whose amplitude or polarity were in fact different (which would be detected in a contrast which maintained the levels of the memory factor). By maintaining the levels of the factor of memory at the second level model, we retained the option to present data using the resultant Dm contrast values, which were easier to present graphically (when not confounded by amplitude and polarity effects), as well as exploring the data for difference in amplitude, polarity etc.

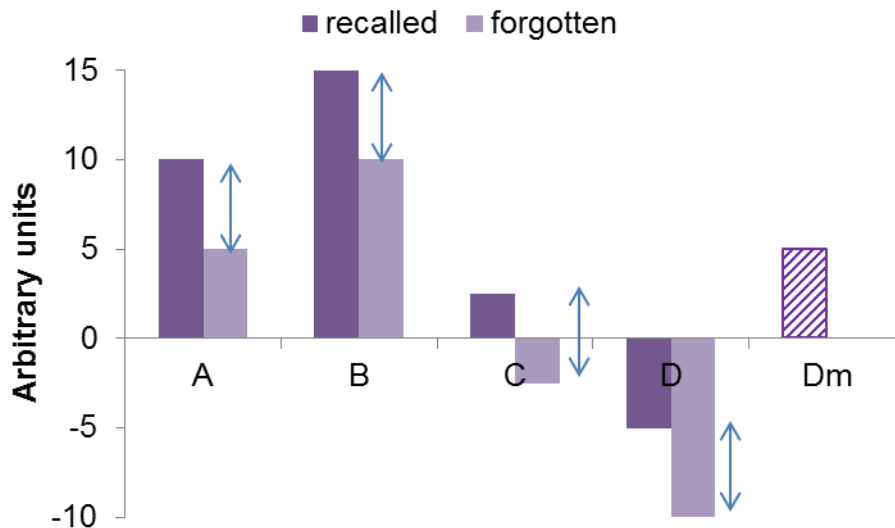


Figure 2.2. Differentiating amplitude and polarity in Dm contrasts

Shows simulated data of four different scenarios in which a calculated Dm contrast would equal +5 (labelled 'Dm', striped bar). Although these hypothetical scenarios all give the same Dm value, by removing the factor of memory from analysis we lose the ability to detect amplitude difference (evident in A compared to B) and polarity differences (A or B compared to D); and polarity differences within the levels of the contrast (remembered compared to forgotten in scenario C) which may be important when making inferences about neural processes.

3. Development of the Semantically Related Emotional and Neutral Stimuli Sets (SeRENS)

Abstract

When measuring memory performance for emotional and neutral stimuli many studies are confounded by not controlling for differential semantic relatedness between stimuli sets. This could lead to the misattribution of the cause of an emotional enhancement of memory effect (EEM), because differential semantic relatedness also contributes to the EEM. Participants rated static visual scenes on subjective measures of arousal, valence, and semantic relatedness. These measures were used to create a novel stimuli set which – in addition to controlling for the standard requirements of an emotionally valenced stimuli set (i.e., significantly higher arousal for emotional items, and significantly different in measures of valence) – also controlled for within-set semantic relatedness, thus resolving a crucial issue that has not previously been addressed in the use of visual stimuli. As an added advantage, the stimuli set developed here are also controlled for measures of objective visual complexity, factors which are also implicated as confounding to the investigation of memory. This article introduces the Semantically Related Emotional and Neutral Stimuli sets (SeRENS) – a collection of emotional and neutral colour images which can be organised flexibly into different sub-sets according to experimental requirements. These stimuli are made freely available for non-commercial use within the scientific community by request.

3.1. Introduction

Dimensional models of emotion suggest that emotions can be classified using two dimensions: arousal and valence (Bradley, Greenwald, Petry, & Lang, 1992; Rubin & Talarico, 2009; Russell, 1980; Watson & Tellegen, 1985). Accordingly, emotional stimuli sets typically consist of emotional stimuli which vary on arousal and are either positive or negative in valence; whereas neutral stimuli typically demonstrate a low level of arousal, and are rated as neither positive nor negative (e.g., International Affective Picture System [IAPS]: Lang, Bradley, & Cuthbert, 1997; 2008). These two dimensions of arousal and valence reliably predict aspects of the emotional experience associated with viewing visual stimuli, such as autonomic responses, and have been used extensively to manipulate emotion reliably in an experimental setting.

While many valenced pictorial stimuli sets are already available (e.g., International Affective Picture System [IAPS]: Lang, Bradley, & Cuthbert, 1997; 2008; Nencki Affective Picture System [NAPS]: Marchewka, Zurawski, Jednoróg, & Grabowska, 2013; Geneva Affective Picture Database [GAPED]: Dan-Glauser & Scherer, 2011), none control for the semantic relatedness or objective visual complexity of the stimuli, which are important because they may influence the dependent measure. By controlling these factors and providing the raw values for these measures we aim to advance the field into line with the quality typical for word stimuli sets, where ratings for many stimulus dimensions have been investigated (e.g., Larsen, Mercer, & Balota, 2006) and made available. For example, the MRC Psycholinguistic Database provides ratings for up to 26 factors for several thousand words (Coltheart, 2007), and software such as the Latent Semantic Analysis (LSA) can

provide a measure of the semantic cohesion of word lists (Landauer & Dumais, 1997; Landauer, Foltz, & Laham, 1998; Dillon, Cooper, Grent-'t-Jong, Woldorv, & LaBar, 2006; Shiffrin, 2003).

3.1.1. Semantic relatedness as a confound to empirical psychological investigation

Based on Tulving's (1979) definition of semantics as understanding or knowledge, we use the term semantic relatedness to refer to the occurrence of a shared meaning among stimuli; which has been operationalised in a number of different ways (Buchanan, Westbury, & Burgess, 2001; Griffiths, Steyvers, & Tenenbaum, 2007; Hunt & McDaniel, 1993; Nelson, Kitto, Galea, McEvoy, & Bruza, 2013). The measurement of semantic relatedness has also been investigated in a variety of ways, for example early investigations used category membership (Cohen, Bousfield & Whitmarsh, 1957; Battig & Montague, 1968; Battig & Montague, 1969, Van Overschelde, Rawson, & Dunlosky, 2004), where participants were given a category title e.g. "seafood" and were asked to write down as many items that should be included in that category as possible. This was not an appropriate method for the current study, as we wanted to measure the participant's assessment of semantic relatedness of stimuli chosen by the experimenter, rather than participants generating their own suggestions. Pair matching procedures have also been employed, in which participants are presented with all possible pairs of stimuli and asked to rate the relatedness of the pairs (e.g. for words: Talmi & Moscovitch, 2004; and pictures: Talmi, Schimmack, Paterson, & Moscovitch, 2007). Although possible with a relatively small number of stimuli, this method would not be appropriate for experiments such as this, where several hundred stimuli would be rated, resulting in over a billion ratings. Previous studies

have also investigated the semantic relatedness of words by using computational methods to estimate cases of word-context congruence and incongruence, which together give a reliable estimate of the semantic relatedness of two or more words (Landauer & Foltz, 1998). We discounted this method for the measurement of semantic relatedness of visual scenes in the current experiment, because pictorial stimuli cannot be found in such semantically bound contexts as can words. Instead we chose to measure the relatedness of stimuli to common exemplars of a given theme (see the Methods section for details).

For the current work, it will be important to draw attention to *within-set* semantic relatedness, which we define as a measure of how well each stimulus of a set represents the given theme, averaged across the stimuli of that set. The within-set semantic relatedness of negative emotional stimuli is often high – many stimuli convey a shared meaning or share a common theme such as war, poverty, and violence. Similarly, these related pictures are more likely to share other properties such as the complexity of the scene (Ochsner, 2000), the presence of people (Talmi, Luk, McGarry, & Moscovitch, 2007) and certain hues such as red (due to many pictures showing bloody scenes). Conversely, neutral stimuli are generally more heterogeneous as they often do not share a common theme and are thus less likely to share common perceptual properties. When investigated empirically, it has been demonstrated that this differential level of semantic relatedness between emotional and neutral stimuli embodies a confound which unduly influences the measure of subsequent memory. One example comes from the emotional enhancement of memory (EEM) literature (Talmi, 2013; Talmi & Moscovitch, 2004). Talmi and Moscovitch (2004) showed participants semantically related emotional, semantically related neutral, and semantically *unrelated* neutral words in separate lists and

measured participant's free recall memory after ~45 minutes. Memory performance for semantically related emotional words was greater than that of semantically unrelated neutral words (resulting in an EEM effect); however, when semantically related emotional words were compared to semantically related neutral words the participant's memory performance was equivalent (i.e. the EEM effect disappeared when lists were matched for semantic relatedness).

In light of this evidence and others (e.g. Balconi & Ferrari, 2012; Buchanan, Etzel, Adolphs, & Tranel, 2006; Madan, Caplan, Lau, & Fujiwara, 2012; Schwarze, Bingel, & Sommer, 2012; Siddiqui & Unsworth, 2011; Sommer, Gläscher, Moritz, & Büchel, 2008; Talmi, Luk, McGarry, & Moscovitch, 2007; Talmi, Schimmack, Paterson, & Moscovitch, 2007) showing the contribution of semantic relatedness to the EEM effect for both verbal and pictorial stimuli; and in light of many studies referring to this effect by way of interpretation of their findings without explicit use of semantically related stimuli sets (Kalpouzos, Fischer, Rieckmann, MacDonald, & Bäckman, 2012; Maratos, Allan, & Rugg, 2000; Verde, Stone, Hatch, & Schnall, 2010; Wang & Fu, 2011) the need for a stimuli set controlling for this confound is evident. This is the primary aim of the present study.

3.1.2. Visual complexity as a confound to empirical psychological investigation

In addition to semantic relatedness, other dimensions that may vary between the stimuli sets should also be considered. One such dimension is visual complexity. Indeed, several studies using emotional images have attempted to control for variability in visual complexity (e.g., Kensinger, Garoff-Eaton, & Schacter, 2007;

Kensinger, Piguet, Krendl, & Corkin, 2005; Ochsner, 2000; Sakaki, Niki, & Mather, 2012; Talmi, Luk, et al., 2007). This can be particularly important since visual complexity has been shown to influence memory (e.g. Isola, Xiao, Parikh, Torralba, & Oliva, 2013; Nguyen & McDaniel, 2014). As findings suggest that subjective ratings of visual complexity (Madan, Bayer, Gamer, Lonsdorf, & Sommer, under review) and vividness (Todd, Talmi, Schmitz, Susskind, & Anderson, 2012) can be biased by emotion, it is preferable to use computational methods to objectively measure visual complexity. Here we operationalize visual complexity using three objective, computational metrics: edge density (amount of image that is detected as 'edge'), feature congestion (clustering of visual details), and subband entropy (disorganisation in the image, inversely related to spatial repetitions) (Madan et al., under review; Rosenholtz, Li, & Nakano, 2007). While some researchers have used JPEG file size as an index of visual complexity, Madan et al. (under review) found that the computational methods inspired by early visual processes (edge density, feature congestion, subband entropy) were better indices of visual complexity and were able to account for all of the variance explained by JPEG file size.

3.2. Method

3.2.1. Participants

Thirty-three undergraduate Psychology students from the University of Manchester were invited to take part in this study for course credit. One participant was excluded from all analyses due to not following task instructions. Four additional participants did not complete Task 2 (relatedness task). Thus, analyses of Task 2 (relatedness

task) comprised of 28 participants (mean age = 19 years, 2 males), and analyses of Task 1 (emotion task) comprised of 32 participants (mean age = 19 years, 4 males);

This study was approved by the University Research Ethics Committee at the University of Manchester. Due to the high number of emotional stimuli presented in this experiment a distress policy was developed for use in this study. The function of this policy was to monitor the progression of participants through the tasks of the experiment, to monitor the mood of participants, and acted as an indicator for the reporting adverse events (available upon request). As part of this policy, participants made subjective ratings on four measures using 9-point scales of – Bored-Engaged, Unhappy-Happy, Anxious-Calm, Miserable-Cheerful – before and after the experiment. Adverse events were defined as a) situations where testing was curtailed due to participant distress, or b) where the participant completed testing but indicated that their mood was lower than their first rating (levels 1 – 2 on the scale) and that their mood did not improve after following the guidance specified in the distress policy. No adverse events were recorded during this experiment.

3.2.2. Materials

786 colour pictures¹ (size 280 x 210 pixels) of equal numbers emotional (n=384) and neutral (n=384) scenes were selected using Google images and supplemented with images from the IAPS (Lang, Bradley, & Cuthbert, 1997; 2008). IAPS pictures were

¹ Many of the selected stimuli were images with no copyright restrictions. In accordance with UK copyright law, the stimuli which were copyrighted may be used here and re-used when intended for non-commercial purposes. Due to the volume of stimuli, we are not able to acknowledge the sources of all stimuli.

cropped to size 280 x 210 pixels, but no other picture processing steps were applied (e.g. re-centring, etc.).

The emotional scenes were negatively valenced, arousing emotional scenes, and these were chosen exclusively because the dominant modulation model of the EEM posits that arousal drives the effect (McGaugh 2004), rather than valence being the most important factor. Recent human models of EEM (Mather et al., 2015) also propose a central role for arousal rather than valence. In addition to this, evidence from neuroimaging studies suggests that there may be a brain basis for selecting only negative stimuli: that negative stimuli elicit stronger (greater amplitude); and/or more reliable activations in the brain. For example, electroencephalography (EEG) studies suggest that negatively valenced, emotional stimuli elicit a greater amplitude electrophysiological response than do positively valenced emotional stimuli (Dolcos & Cabeza, 2002; Kaestner & Polich, 2011), especially when investigating the differential emotional electrophysiological correlates of subsequent memory (Righi et al., 2012); but see Olofsson, Nordin, Sequeira, & Polich (2008); and Schupp, Flaisch, Stockburger, & Junghofer (2006). Moreover, a recent meta-analysis (Lindquist, Satpute, Wager, Weber, & Barrett, 2015) investigating neuroimaging evidence for the representation of emotion in the brain found that although a network of brain areas could be identified as responding to emotion per se (i.e. both negative and positive); it was found that negative stimuli more frequently elicited activity in some of those areas compared to positive stimuli; however none of those areas were more frequently activated by positive compared to negative stimuli. Finally, many studies investigating emotion have often used only negatively valenced stimuli, rather than both negative and positive emotional stimuli (e.g. Maratos et al., 2000; Pottage & Schaefer, 2012; Schaefer et al., 2002; Schwarze et al., 2012; Talmi, Luk, et al., 2007;

Talmi & McGarry, 2012; Taylor et al., 1998; Todd, Evans, Morris, Lewis, & Taylor, 2011; Watts, Buratto, Brotherhood, Barnacle, & Schaefer, 2014), setting a precedent for the use of such stimuli.

Neutral scenes were selected based on the theme ‘domestic scenes’ following the previous work of our lab (e.g. Talmi, Schimmack, et al., 2007). Choosing a theme such as this allowed the selection of a large number of stimuli whilst maintaining the probability of semantic relatedness. Neutral images were selected to be complex scenes and most depicted people. For example, most stimuli contained a person carrying out an action; and plain pictures of objects (e.g., a hammer on a white background) were intentionally *not* selected. This general primary selection criteria, made it more likely that neutral and emotional stimuli could later be matched on their average outcome measure scores such as visual complexity.

Within each set of emotional and neutral pictures 50% of the images formed “group A” and 50% formed “group B”. Stimuli from group A and B were ‘content-matched’ but not identical. For example if one neutral group A picture depicted a person laying paving, the corresponding neutral group B picture would also contain a non-identical picture showing a similar scene of a person laying paving. Content-matched pictures could be given the same title but were not identical (as in Kensinger et al., 2007). Pictures were selected in this manner to allow future experiments to use content-matched pictures provided as part of SeRENS if required. For example, this may be useful to match targets and lures in recognition memory tests or in ‘same-similar’ paradigms (Kensinger, Garoff-Eaton, & Schacter, 2006; Kensinger et al., 2007).

Nine neutral sub-categories which embodied the theme domestic scenes were defined as follows: Indoor “Do It Yourself” (D.I.Y); Outdoor D.I.Y; cleaning and chores;

leisure scenes; hobbies and games (non-sport); hobbies and games (sporting); gardening; personal hygiene; and working at home. For the emotional scenes, nine sub-categories were defined as follows: law enforcement and armed services; children in danger; injured and wounded; medical scenes; torture; aggravated crime; poverty; death; and accidents, emergencies, and disasters. One picture representing each of these emotional and neutral sub-categories was randomly selected to be used in the 'example matrix' in Task 2, therefore leaving 768 experimental pictures.

3.2.3. Procedure

Each participant took part in two tasks, which we called the emotion task and the relatedness task. In the emotion task participants viewed 768 randomly ordered emotional and neutral pictures displayed on a computer screen one at a time, and were asked to rate each picture for emotional valence (first) and arousal (second) using computerised SAM scales (Bradley & Lang, 1994) presented on-screen, one above the other. The SAM scales have 9 intervals each and range from -4 = 'unhappy' to +4 = 'happy' for the valence scale, and -4 = 'excited' to +4 = 'calm' for the arousal scale (a central interval, '0' marks the mid-point on both scales). This task was self-paced and participants were encouraged to take breaks if needed.

The relatedness task comprised of two parts, reflecting the rating of the emotional and neutral stimuli separately (using the same procedure for each set), with the order counterbalanced across participants. When rating a given set of stimuli (emotional or neutral) participants saw the corresponding example matrix as detailed above, and this remained on the screen throughout the task to serve as an anchor. Participants viewed and rated 422 pictures: 384 were of the same valence as

the example matrix (emotional or neutral), and 38 were from the other valence set. The latter were included as 'catch trials' to ensure that participants were paying attention throughout the experiment. This task was also self-paced and participants were encouraged to take breaks if needed. Participants were first instructed to study the aforementioned nine example pictures of the current set. Participants were advised that the examples shared a common theme or meaning, and were asked to look at the example pictures and think about what this shared meaning may be. After scrutinising the nine examples, participants were instructed to rate the 422 randomly ordered experimental pictures one at a time using a 7-point Likert scale of relatedness, with 1 titled 'low relatedness' and 7 titled 'high relatedness' (as in Talmi & McGarry, 2012; see Figure 3.1); to judge if the trial image was semantically related to the nine examples (for definition of semantic relatedness see Section 1.1 above). The instructions to participants were as follows:

Screen 1:

"In this task you will help us to validate a stimuli set by providing ratings for possible pictures to be included. Nine EXAMPLE pictures of one stimulus set will be displayed throughout the experiment. TRIAL pictures will be presented one at a time and you will be asked to rate how related is the TRIAL to the EXAMPLES. The next screen explains the ratings. Press SPACE BAR to continue."

Screen 2:

"When you rate the relatedness of the TRIAL to the EXAMPLES we want you to focus on whether the overall meaning of the TRIAL and the EXAMPLES are related, i.e. do they convey a similar meaning or a different meaning? We DO NOT want you to consider low-level similarities, such as colours, shapes, number

of objects / people. You will rate the relatedness using a scale of 1-7 which will be displayed on the screen for each trial. Press SPACE BAR to continue.”

The final screen gave an example of the relatedness scale.

After participants completed the relatedness ratings of one valence category (e.g. emotional stimuli), the procedure was repeated with the other set (e.g. neutral stimuli). On average participants took a total of two hours to complete all tasks. This experiment was realised using Cogent 2000 (Wellcome Department of Imaging Neuroscience, UCL, UK; http://www.vislab.ucl.ac.uk/cogent_2000.php).



Figure 3.1. Example trial rating of semantic relatedness as seen by participants
Left: Trial image and relatedness scale. The scale remained on the screen throughout the trial. Right: Nine example images (neutral example matrix). The examples remained on screen throughout the task.

3.2.4. Analysis

For ease of reference we converted the scores of the SAM scales to a scale of 1 – 9 (a common translation from the original ‘-4’ to ‘+4’ scaling used in Bradley & Lang, 1994); where for the valence scale the converted score of ‘1’ corresponded to the SAM

scale score of -4 (unhappy) and the converted score of '9' corresponded to the score of to '+4' (happy). For the arousal scale a converted score of '1' corresponded to '+4' (calm) and a converted score of 9 corresponded to a SAM scale score of '-4' (excited). For both converted scales, a score of '5' represented the mid-point.

Responses from each participant for the emotion task ($n=32$), and the relatedness task ($n=28$) were averaged across participants for each picture. To determine the reliability of the measures used, Cronbach alpha scores were calculated. Reliability was high for all subjective measures: arousal $\alpha=.99$; valence $\alpha=.98$; relatedness $\alpha=.99$. For analysis purposes we used mean scores of arousal, valence, and semantic relatedness, averaged across participants, for each stimulus (in line with previous reporting of statistical testing of novel stimuli sets e.g. Dan-Glauser & Scherer, 2011; Lang et al., 1997; Marchewka et al., 2013).

For stimulus selection, emotional pictures were removed from analysis if their average arousal score was less than 5, their average valence score was greater than 4, and their average relatedness was less than 4 (for the relatedness ratings scale the score of '4' represented the mid-point). Neutral items were removed if their average arousal score was greater than 4, their average valence score was less than 4 or greater than 6, and their average relatedness score was less than 4.

Visual complexity was calculated using three computational methods: edge density, feature congestion, and subband entropy. Edge density is based on identifying boundaries between objects and features within an image. Here we converted the images to CIELab 1976 colour space (designed to mimic the responses of the human eye) and then computed the Canny edge detection on the L^* dimension using the lower and upper thresholds suggested by Rosenholtz et al. (2007), 0.11 and 0.27, respectively. Feature congestion quantifies how 'cluttered' an image is and

incorporates colour, luminance contrast, and orientation (computed using the MATLAB code provided with Rosenholtz et al., 2007). Subband entropy quantifies the ‘disorganisation’ within the image, through Shannon’s entropy in spatial repetitions of hue, luminance, and size (i.e., spatial frequency; also computed using MATLAB code from Rosenholtz et al., 2007).

For stimulus selection, stimuli were removed from further analyses if they were identified as outliers on any one (or more) of the measures: arousal, valence, semantic relatedness, edge density, feature congestion, or subband entropy. Outliers were identified by any score greater than or less than 2.5 standard deviations from the mean, following Thompson (2006). A quality control procedure was also carried out, whereby any two remaining stimuli from the same set that were deemed too alike were identified and one stimulus removed (stimuli which were both from set A or both from set B within one valence set, which were not intentional duplicates, but nevertheless could be considered so). We also removed stimuli which were deemed to be of a poor quality (e.g., due to obvious pixelation or distortions). In order to obtain the desired outcomes – namely statistical differences between emotional and neutral items for arousal and valence, and no statistical differences between emotional and neutral items for semantic relatedness and visual complexity measures – we removed the 25 neutral stimuli with highest subband entropy measures; and 25 further neutral stimuli whose semantic relatedness measures were highest.

The remaining stimuli were then organised into two final sets which we called the SeRENS Emotional and SeRENS Neutral (see Figure 3.2 for flow diagram of stimulus selection).

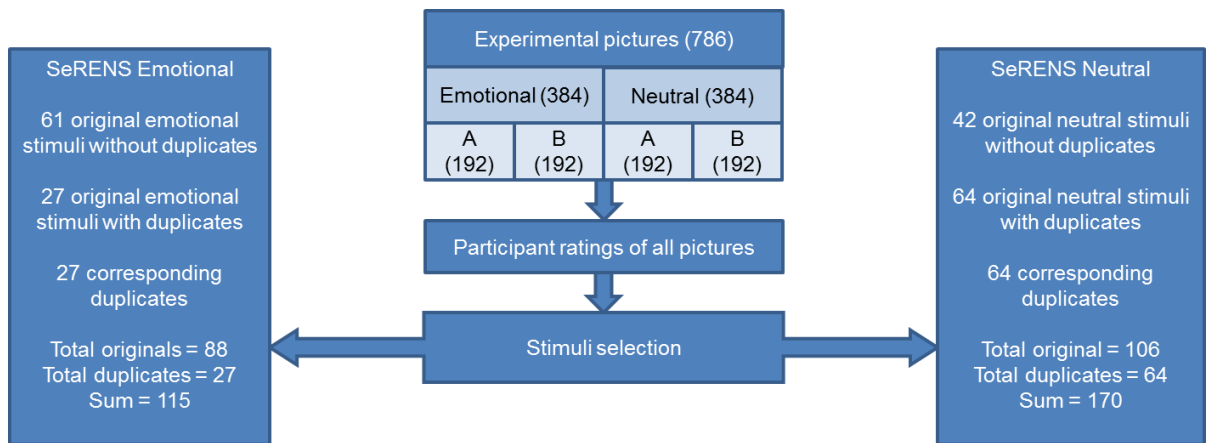


Figure 3.2. Diagram showing process of stimuli set creation

See analysis section for detailed description of the stimuli selection.

After stimulus selection the number of remaining emotional stimuli from either group A or B was 88, and these stimuli formed part of the SeRENS Emotional stimuli set. For clarity, these pictures will be referred to as ‘originals’ to distinguish them from their corresponding content-matched stimuli referred to as ‘duplicates’. Of these original stimuli, 27 were determined to have a corresponding content-matched stimulus which also passed the selection procedure. Therefore, the SeRENS Emotional set contains 115 emotional stimuli (88 originals and 27 duplicates). Of the SeRENS Emotional originals, 22 were taken from the IAPS (Lang, Bradley, & Cuthbert, 1997; 2008; [2205, 2800, 3015, 3030, 3051, 3102, 3110, 3120, 3170, 3266, 3500, 3550, 6212, 6315, 6550, 9042, 9250, 9253, 9400, 9420, 9433, 9921]).²

The number of remaining neutral stimuli from either group A or B was 106, and these stimuli therefore formed the SeRENS Neutral stimuli set. Of these stimuli, 64 had a corresponding content-matched stimulus which passed the selection

² These pictures are not supplied as part of the SeRENS and permission should be sought from <http://csea.phhp.ufl.edu/media/iapsmessage.html> in order to use these stimuli to supplement the SeRENS, or otherwise SeRENS could be used without them.

procedure. Therefore the SeRENS Neutral set contains 170 neutral stimuli (106 originals and 64 duplicates). Table 3.1 provides grand average arousal, valence, and semantic relatedness scores (averages were generated across participants per stimuli, and then averaged across stimuli to provide one grand average score for each measure per valence, and per set); plus objective measures of visual complexity (as described above).

To determine whether there existed a significant difference in the measures of arousal, valence, semantic relatedness, and objective measures of visual complexity between emotional and neutral stimuli, we conducted independent-samples t-tests, which treated the stimuli as cases. Analyses were performed separately for originals and duplicates. Consistent with reporting of new stimuli sets in the literature (Danglauser & Scherer, 2011; Lang et al., 1997; Marchewka et al., 2013) we also represent the pictures in arousal-valence space (see Figure 3.3), and test the correlation of arousal and valence using the Pearson correlation coefficient.

Table 3.1. Properties of the final SeRENS images

		<i>n</i>	A	V	SR	VC-ED	VC-FC	VC-SE
Originals	Emotional	88	5.99 (0.67)	2.60 (0.44)	4.98 (0.47)	0.07 (0.02)	4.66 (1.18)	3.07 (0.22)
	Neutral	106	2.35 (0.20)	5.41 (0.33)	5.00 (0.45)	0.07 (0.02)	4.94 (1.06)	3.06 (0.13)
Duplicates	Emotional	27	5.92 (0.52)	2.69 (0.40)	4.95 (0.50)	0.06 (0.02)	4.55 (1.56)	3.02 (0.27)
	Neutral	64	2.36 (0.18)	5.41 (0.31)	4.99 (0.43)	0.06 (0.02)	4.77 (1.01)	3.01 (0.18)

Mean scores averaged across stimuli are reported, standard deviation in parentheses. n = number of stimuli; A = Arousal; V = valence; SR = semantic relatedness; VC = visual complexity; ED = edge density; FC = feature congestion; SE = subband entropy.

3.3. Results

3.3.1. Originals

Analysis comparing the original emotional ($n=88$) and neutral ($n=106$) stimuli revealed a significant difference in the average arousal score. Emotional stimuli measured higher on arousal ($M = 5.99, SD = 0.67$) than neutral stimuli ($M = 2.35, SD = 0.20$), $t(192) = 48.97, p < .001$, 95% CI [3.48, 3.77], Cohen's $d_s = 7.63$. Analysis also identified a significant difference in the average valence scores of emotional and neutral stimuli. Emotional stimuli measured lower on valence, i.e. were more negatively valenced ($M = 2.60, SD = 0.44$) than neutral stimuli ($M = 5.41, SD = 0.33$), $t(192) = 49.15, p < .001$, 95% CI [-2.93, -2.71], Cohen's $d_s = 7.35$ (effect sizes calculated according to resources from Lakens, 2013). As expected, there was no significant difference in the average relatedness scores of emotional and neutral stimuli ($p = 0.70$). There was also no significant difference between emotional and neutral stimuli for the visual complexity measures (edge density: $p = 0.06$; feature congestion: $p = 0.08$; subband entropy: $p = 0.91$).

3.3.2. Duplicates

Analysis comparing the duplicate emotional ($n = 27$) and duplicate neutral stimuli ($n = 64$) again revealed a significant difference in the average arousal scores. Emotional stimuli measured higher on arousal ($M = 5.92, SD = 0.52$) than neutral stimuli ($M = 2.36, SD = 0.18$), $t(89) = 34.32, p < .001$, 95% CI [3.36, 3.77], Cohen's $d_s = 10.98$. Emotional stimuli measured lower on valence, i.e. were more negatively valenced ($M = 2.69, SD = 0.40$) than neutral stimuli ($M = 5.41, SD = 0.31$), $t(89) = 31.25, p < .001$,

95% CI [-2.90, -2.56], Cohen's $d_s = 7.96$. As intended, there was again no significant difference in the average relatedness scores of emotional and neutral stimuli ($p = 0.67$), and no significant differences for any of the measures of visual complexity (edge density: $p = 0.87$; feature congestion: $p = 0.46$; subband entropy: $p = 0.87$).

To ensure that the corresponding original and duplicate stimuli were adequately matched we performed independent-samples t-tests for all measures comparing original and duplicates within valence. Consistent with adequately matched stimuli, we found no significant differences between originals and duplicates for emotional or for neutral stimuli on any measures. We also checked that participants could identify the 'catch trials' (different-valence trials) in the relatedness task; and as expected we found that these trials were reported as significantly less related to the example matrices than the same-valence stimuli (emotional stimuli: $t(420) = 12.39, p < .001$, Hedges's $g_s = 2.09$; neutral stimuli: $t(420) = 26.76, p < .001$, Hedges's $g_s = 4.54$).

3.3.3. Correlations

In line with publications introducing other affective stimuli sets (Lang et al., 1997; Marchewka et al., 2013) we also investigated the correlation of arousal and valence for all stimuli (averaged over participants) within SeRENS Emotional and SeRENS Neutral (including duplicates). For SeRENS Emotional we found a significant negative correlation between these two measures $r = -.862, p = <.001$, demonstrating that as ratings of arousal increased, so too did ratings of valence decrease (i.e arousing stimuli were rated as more negative in valence). For SeRENS Neutral there was no

significant correlation between the measures of arousal and valence $r = .094$, $p = .22$ (see Figure 3.3).

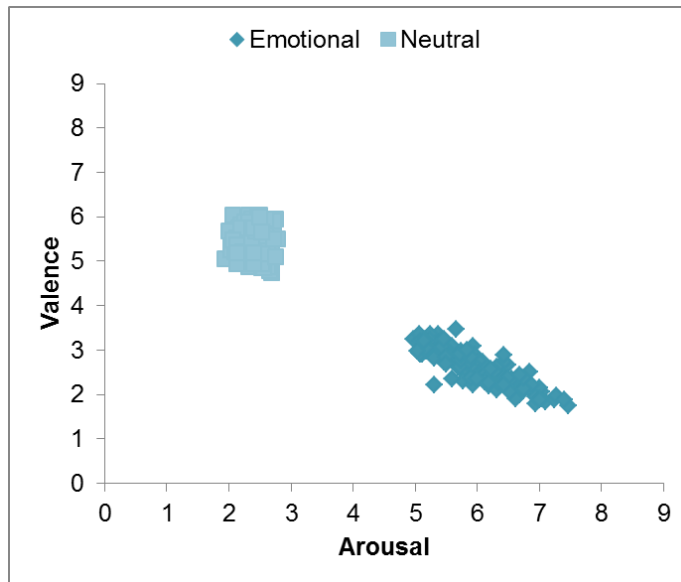


Figure 3.3. Plotting the SeRENS stimuli in Arousal-Valence Space

x and y axes denote average scores based on the SAM scale ratings (see text for details of testing).

3.4. Discussion

The final emotional stimuli selection comprise stimuli of high arousal, negatively valenced, colour pictures; with the final neutral stimuli selection comprising low arousal, neutral valence, colour pictures; and all sets have high within-set semantic relatedness. Emotional and neutral sets significantly differ on measures of arousal and valence, and – as intended – are not significantly different on measures of semantic relatedness and visual complexity. By controlling for semantic relatedness and three objective measures of visual complexity, we can assert that any differences in behavioural response (and/or other physiological measures) to SeRENS Emotional and Neutral are not confounded by these measures; allowing researchers more confidence that any differences are due to emotion – the manipulation of interest. The SeRENS also convey an advantage over existing stimuli sets as they are supplied with

a number of duplicates, which may prove useful for example when testing memory using recognition paradigms.

3.4.1. Correlation of Arousal and Valence

As demonstrated in Figure 3.3 and evidenced by correlational analysis, the SeRENS Emotional images exhibited a significant negative correlation between the measures of valence and arousal. That is to say, that like other stimuli sets (Marchewka et al., 2013), as the average rating of valence for a given stimulus decreased (i.e., the stimulus was perceived as more negative), the average rating of arousal for the same picture increased (i.e., the stimulus was perceived as more arousing). Like the NAPS (Marchewka et al., 2013), SeRENS demonstrates a linear relationship between valence and arousal which is different from the 'boomerang-shaped' pattern which represents the correlation of arousal and valence for the IAPS (Lang et al., 1997; 2008). This difference is due to the fact that SeRENS contains no positively valenced stimuli (or in the case of Marchewka et al., 2013; no positive and arousing stimuli). Another difference between the spread of arousal and valence for the SeRENS compared to other published stimuli sets such as IAPS (Lang et al., 1997; 2008), the NAPS (Marchewka et al., 2013), and the GAPED (Dan-Glauser & Scherer, 2011) is that the parcellation in arousal and valence space for each set is more distinct in SeRENS (i.e., the limits of arousal and valence are not overlapping between emotional and neutral stimuli). This may be advantageous in some studies because it suggests that based on the arousal and valence scores, the stimuli are clearly categorised as either emotional or neutral. This means that we can be reasonably confident that no emotional stimulus would be incorrectly identified as neutral and vice versa; providing extra confidence of homogeneity within sets, which should translate to

more reliable results of emotional manipulation in future experiments. On the other hand, future studies may require stimuli representing a more continuous progression through the arousal and valence scales; and this would be possible with careful stimulus selection from SeRENS – however other stimulus sets may be more appropriate for this requirement. Researchers planning future studies could weigh this requirement with that of the experimental benefits of SeRENS, i.e. the control of semantic relatedness and visual complexity.

3.4.2. Methodological evaluation

The objective measures of visual complexity used here were deemed to be optimal in comparison to subjective ratings of visual complexity, which is susceptible to cognitive and emotional biases. This was demonstrated by Madan et al. (under review) which showed that subjective ratings of visual complexity correlated with arousal and valence ratings, while measures of objective visual complexity did not. Though other objective measures of visual complexity have also been used (e.g., JPEG file size), the measures used here were preferred as they are thought to better model processes shown to occur in early visual cortices and have been shown to capture more inter-item variability (Madan et al., under review). As visual complexity has been found to influence memory (e.g., Isola et al., 2014; Nguyen & McDaniel, in press), but is often considered to be orthogonal to emotion, it is preferable to minimize this additional source of variability, as we have here. More generally, our ability to control for stimulus properties is more limited for pictorial stimuli than for words. As stated earlier, the MRC Psycholinguistic Database provides ratings for up to 26 factors

(Coltheart, 2007). By providing the SeRENS stimuli with additional experimental controls, we hope to improve the precision and robustness of future studies.

Given the unsuitability of previous methods to test semantic relatedness, we created an alternative novel method to measure semantic relatedness. This avoided inappropriate methods such as computational models – popular for assessing the semantic relatedness of words, and which require common contexts (LSA, Landauer & Foltz, 1998); and pair matching (Talmi, Schimmack, et al., 2007) – which would have resulted in an inordinate number of trials (over a billion ratings for the current sets). This method was intentionally designed such that in the final sets no single stimulus or specific combination of stimuli was crucial for the integrity of the within-set semantic relatedness of each set. Because every trial stimulus was judged for its relatedness to a matrix of exemplars for that set, all stimuli judged to be highly related to the exemplars would necessarily be highly related to each other. Therefore, if researchers wished to utilise only a subset of the SeRENS from a given set, the probability of significantly altering the within-set semantic relatedness scores remain low (although statistical verification of this should be sought when selecting any subset of SeRENS). A unipolar Likert scale of semantic relatedness ranging from 1-7 (as in Talmi & McGarry, 2012) allowed participants to be specific in their responses, whilst avoiding an overwhelming large or obviously contrived scale (as every same-set picture was designed to be semantically related to the example set on which their rating was based). Being unipolar, the scale created a ‘forced choice’ situation – i.e. there was no option to respond ‘not sure’ or ‘don’t know’ (which participants often mistake as the midpoint of bi-polar scales), ensuring all stimuli were accurately rated.

3.4.3. Flexibility of stimuli selection for future studies

In contrast to the stringent matching process undertaken to create SeRENS, there remains an important flexibility of stimulus selection for future studies, which represents a considerable advantage. This flexibility is due to the experimental design regarding relatedness measures (see discussion of methods above), supplementary information, and the provision of duplicates.

Appendix A provides the arousal, valence, semantic relatedness, and visual complexity measures for each individual stimulus, averaged across participants. This aids the flexibility of stimulus selection for future studies, allowing researchers to hand-pick a subset of stimuli from SeRENS according to experimental need, and to verify the statistical significance of important measures.

A further benefit of SeRENS which contributes to the flexibility of the set is the provision of content-matched duplicates. The duplicates are content-matched but not identical stimuli, which convey the same properties as their corresponding original stimulus; as verified by statistical significance testing which verified no significant differences between original and duplicates on any measure. As well as ensuring no significant differences between originals and corresponding duplicates, we have verified that the emotional and neutral duplicates differ statistically on measures of arousal and valence, but not on semantic relatedness or measures of visual complexity – following the same pattern of significant differences as the original sets. Duplicates will be useful in future research which aims to test memory using recognition paradigms, for example where participants would be presented with a mixture of “old” (seen before) stimuli which they are required to distinguish from “new” (previously unseen) stimuli. Using content-matched lures presents an

advantage over randomly selected lures because they test a higher level of accuracy of recognition, ensuring that the participant recognises a stimulus specifically, over and above the vague content of (or a familiarity with-) the stimulus. Of course, the SeRENS could equally be used without the duplicates, for example, in experiments which test memory using other methods such as free recall.

Finally, it is noted that the experience of emotion is a complex and multi-faceted phenomena which challenges scientific investigation. The definition of emotion has been contested (Izard, 2010), and a number of theoretical frameworks compete to describe it (Damasio, Everitt, & Bishop, 2007; Ekman, 1992; Lazarus, 1991b; Russell, 1980). Recent compelling evidence advocating the existence of mixed emotions (feeling two 'opposite' emotions at the same time; Berrios, Totterdell, & Kellett, 2015) also pose a challenge to these models. As such there are many potential influences of emotional experience and emotional memory, and therefore these stimuli sets are limited in that they address a finite number of contributory factors. Providing these novel, modern, validated emotional and neutral stimuli sets will expand the choice of valenced pictorial stimuli; and should encourage experimenters to control for differential semantic relatedness and visual complexity in future research.

3.5. Conclusion

Our experiment resulted in two stimuli sets that will be optimal for use in experiments where otherwise differential semantic relatedness and/or visual complexity may prove confounding to the interpretation of the dependent measure, such as the measurement of memory performance (Talmi & Moscovitch, 2004; Isola

et al., 2014). As far as we are aware this is the only stimuli set of this nature, and therefore is likely to serve as an important resource for researchers of emotional memory.

4. Using EEG to investigate the contribution of distinctiveness processing to the immediate emotional enhancement of memory.

Abstract

The emotional enhancement of memory (EEM) effect is typically explained by citing consolidation as the key process, however recent research suggests that cognitive factors before consolidation may also play an important role. When semantic relatedness and attention are equated the EEM arises only in mixed lists, said to engender the state of distinctiveness processing: sustained cognitive effort applied to encoding of stimuli with changing properties (valence). To understand how distinctiveness processing might contribute to the EEM we investigated the electrophysiological (EEG) correlates of a list-type manipulation at encoding with a subsequent memory paradigm. Participants encoded semantically related emotional and neutral scenes in pure and mixed lists, whilst EEG was recorded. EEG data revealed a significant list type x EEM interaction evident in a broad topography spanning frontal to posterior mid-line and right lateralised scalp sites from ~300ms post-stimulus. Our results demonstrate that the processing of a given stimulus is modulated by the encoding list, suggestive of unique list-dependent processing, which in mixed lists may represent distinctiveness processing. Mixed list processing was characterised by effects in an early attention component (P300), and the late positive potential relating to working memory and stimulus elaboration (LPP; 800-1500ms); which both contributed to successful emotional- but not neutral- item encoding. Consistent with our behavioural results, this demonstrates an electrophysiological correlate of the modulation of the EEM by list type. A potential mechanism explaining the contribution of distinctiveness processing to the EEM is discussed.

4.1. Introduction

Noted as one of the most adaptively significant types of memory, emotional memory has been the focus of much investigation. Research has extensively investigated the process of preferential consolidation for emotional information (the modulation model - McGaugh, 2004), however emerging research also indicates a beneficial effect for emotional information evident before consolidation (Dolcos & Cabeza, 2002; Kern, Libkuman, Otani, & Holmes, 2005; Ritchey, Labar, & Cabeza, 2010; Talmi & McGarry, 2012; Watts, Buratto, Brotherhood, Barnacle, & Schaefer, 2014). This body of research demonstrates that the emotional enhancement of memory (EEM) effect is evident even at short retention intervals, at a time before consolidation has occurred. Mediation theory (Talmi, 2013) suggests that emotional and neutral information differentially recruit cognitive processes at the time of encoding and retrieval, which contributes to the greater memory for emotional compared to neutral information. The EEM effect may therefore be explained using either one of these models, but a unified model is yet to be developed. To this end, the current experiment aims to better-characterise the distinctiveness processing list-type effect as it contributes to the EEM; thus adding to the development of a unified theory of the EEM effect with data regarding cognitive processes.

4.1.1. The influence of cognition on the EEM effect: Distinctiveness processing and semantic relatedness

Distinctiveness processing is the state of sustained cognitive processing which may occur during encoding when neighbouring stimuli exhibit changing properties, such as valence, over a series of consecutive trials (Hunt & McDaniel, 1993). One way of

operationalising distinctiveness processing is to create pure lists where stimuli share a common property such as valence, therefore minimising distinctiveness processing; and mixed lists where some stimuli contain non-common properties (variation in valence), a condition which induces greater distinctiveness processing. Although well-defined as psychological construct, the properties of distinctiveness processing are unknown. As our every-day experiences are more akin to mixed list conditions, it is important to investigate if- and how- this distinctiveness processing state contributes to the EEM.

One viable explanation of EEM which relates to distinctiveness processing at encoding is the Arousal-Biased Competition (ABC) theory (Mather & Sutherland, 2011). In ABC Theory, arousal acts to increase the competition between items for memory-supporting resources such as perception. The memorial outcome of this state of competition induced by arousal is determined by the priority assigned to each item, on the basis of top-down and bottom-up processing. When participants encode emotional stimuli, bottom-up processes induce a prioritization of these stimuli, evident in an involuntary increase of attention to these items (Talmi, Schimmack, Paterson, & Moscovitch, 2007; Pottage & Schaefer, 2012; for a review see Schupp, Flaisch, Stockburger, & Junghofer, 2006). Importantly, according to ABC theory this competitive process only occurs in mixed not pure lists, as presumably uniform levels of arousal in pure emotional lists cannot lead to substantial competition, therefore approximately equal amounts of processing resources should be allocated to each item. ABC theory therefore predicts both that in mixed lists emotional stimuli would receive a greater allocation of processing resources (such as attention and working memory), compared to neutral stimuli, and compared to pure lists – a difference that would account for the EEM effect in mixed lists. The current study will test this

prediction of ABC theory by examining the electrophysiological correlates of the successful encoding of emotional and neutral stimuli in mixed and pure lists.

Another cognitive factor known to influence the EEM effect is the degree of interrelatedness – or semantic relatedness – within stimuli sets. Semantic knowledge refers to our understanding of the world around us, and the things and people in it (Tulving, 1972); and therefore in an experimental setting semantic *relatedness* may be thought of as our understanding of how one stimulus is related to another. In other words, we use semantic relatedness to refer to the coherence, similarity or thematic (sub-) grouping between stimuli. Emotional stimuli sets are noted to be inherently more semantically related compared to neutral sets because they tend to contain repeated themes which denote a shared understanding of the stimuli (such as violence, poverty etc.). Conversely, neutral scenes vary considerably more and are likely to contain a wider range of themes (leisure, landscapes, tools etc.) which do not represent a shared understanding. Research on the EEM effect shows that when controlled for semantic relatedness and attention, ‘pure’ lists (no distinctiveness processing) containing either only emotional or only semantically related neutral stimuli, are recalled equally well, meaning that no EEM is found (e.g. Buchanan, Etzel, Adolphs, & Tranel, 2006; Sommer, Gläscher, Moritz, & Büchel, 2008; Talmi & Moscovitch, 2004; Talmi et al., 2007; Talmi & McGarry, 2012). This is in direct contrast to the evident EEM effect in pure lists when semantic relatedness is not controlled (Talmi, Schimmack, et al., 2007; Watts et al., 2014). Consequently it is evident that the degree of semantic relatedness has a significant impact on the EEM effect, and as such is a potential confound. Therefore this factor will be controlled in the current experiment, in order to best isolate effects due to the list type manipulation (mixed versus pure lists).

To understand how to test the contribution of distinctiveness processing to the EEM whilst controlling for within-set semantic relatedness using EEG, we must first understand how EEG data characterises successful memory, and how the manipulation of emotion can modulate these characteristics.

4.1.2. Electrophysiology of memory and the EEM

In order to investigate the contribution of cognitive factors to the EEM at the time of encoding, one can examine the changes in electrophysiological activity in the brain using a subsequent memory paradigm (Paller, Kutas, & Mayes, 1987); see Chapter 2 – General Methodology. Using this method, neural responses at encoding are sorted post-hoc into ‘remembered’ or ‘forgotten’ events following the participant’s performance at retrieval; resulting in specific behavioural responses coupled with associated neural encoding activity. EEG research has identified robust and replicable correlates of successful subsequent memory (the subsequent memory effect or “SME”: brain activity greater for remembered compared to forgotten events; also known as the ‘Dm’ effect, or difference due to memory) and delineated how this may be modulated by emotion – the EEM effect. To this end, free recall has been noted as a particularly well-suited memory test due to the greater reliability of eliciting the Dm effect compared to other methods such as recognition (Johnson, 1995); and as such was employed in the current design.

In relation to the electrophysiological correlates of memory, the Dm effect may be found at frontal, central, and midline scalp sites from 300ms extending beyond 1200ms (Coles & Rugg, 1995); and is typically evident in two event-related potential (ERP) components: the P300 (Palomba, Angrilli, & Mini, 1997; Polich, 2007; Wagner,

Koutstaal, & Schacter, 1999; Watts et al., 2014) and the late positive potential (LPP; Friedman & Johnson, 2000; Paller & Wagner, 2002; Sanquist, Rohrbaugh, Syndulko, & Lindsley, 1980). The P300 is noted as a positive-going waveform with a peak amplitude at 300-600ms post-stimulus; and the LPP is a positive-going sustained slow-wave component, typically apparent from 400ms post-stimulus. In relation to memory, both components are found at central mid-line and central parietal sites; with remembered items demonstrating a more positive-going ERP waveform than forgotten items (Palomba, Angrilli, & Mini, 1997; Fabiani & Donchin, 1995; Gutchess, Ieui, & Federmeier, 2007; Kaestner & Polich, 2011; Karis, Fabiani, & Donchin, 1984; Weinberg & Hajcak, 2010; Weymar, Löw, Schwabe, & Hamm, 2010). Differences in the latency of the Dm effect have been attributed to specific processes supporting memory. Differences in the P300 component are said to reflect differential attentional allocation predictive of subsequent memory (Codispoti, Ferrari, & Bradley, 2007; Polich, 2007; Watts et al., 2014). Differences in an 'early' section of the LPP (400ms to 800ms) are also considered to be caused by a difference in allocation of attentional resources which has been related to differential semantic processing leading to greater memory (Paller & Wagner, 2002; Sanquist et al., 1980). 'Late' sustained LPP (also termed slow wave effects) from approximately 800ms onwards present at midline sites relate to tasks requiring working memory resources, and the maintenance or manipulation of representations in working memory (Azizian & Polich, 2007; Mangels, Picton, & Craik, 2001).

An appraisal of previous research investigating the Dm effect suggests that the LPP is highly sensitive to task, showing spatial and temporal variations which is thought to embody the many ways in which encoding may be enhanced (Otten & Rugg, 2001). Due to the apparent task-dependent nature of the LPP it is reasonable to

assume that distinctiveness processing may modulate this particular component. Specifically, because ABC theory suggests that emotional items recruit both attention and additional working memory resources under distinctiveness processing conditions (mixed lists), and because mediation theory also predicts increased cognitive resources during encoding of emotional items, we predicted that a list-type manipulation would modulate the morphology of the LPP in the current study.

With regards to the electrophysiological correlates of emotion, emotional items have been shown to modulate the amplitude of ERP components with little change in latency (Olofsson et al., 2008). A commonly observed modulation of the ERP by *emotion* is a greater LPP amplitude for emotional- relative to neutral- stimuli at midline centroparietal scalp sites (e.g. Weinberg & Hajcak, 2010; for reviews see Olofsson et al., 2008; and Schupp, Flaisch, Stockburger, & Junghofer, 2006). It is also thought that greater amplitude LPPs elicited by emotional stimuli may reflect differences to the established context (e.g. the processing of emotional items within an established neutral context; Schupp et al., 2000). Unsurprisingly then, although memory and emotion may both modulate the LPP independently, the EEM is evident in the LPP component demonstrating a greater amplitude LPP for recalled compared to forgotten emotional stimuli, and compared to neutral stimuli (Dolcos & Cabeza, 2002; Righi et al., 2012). Based on this evidence, we predict that modulations of early and late LPPs would be observed in analyses where EEM and list type interact.

Our previous work on distinctiveness processing and EEM using EEG (Watts et al., 2014) demonstrated a cancelling of the Dm effect in posterior sites for neutral items in mixed compared to pure lists between 200 and 400ms, and between 800 and 1500ms. In accordance with ABC theory (Mather & Sutherland, 2011) and mediation theory (Talmi, 2013) the morphology of these effects suggests that in mixed lists

neutral items received less attention and working memory resources (Watts et al., 2014). In contrast with these theories, there was no difference between the Dm effect for emotional stimuli in pure compared to mixed lists (whereas the theories cited here predict emotional $Dm_{\text{mixed}} > \text{emotional } Dm_{\text{pure}}$). However, it is notable that the stimuli used by Watts et al., (2014) were not controlled for semantic relatedness, which represents a confound to the investigation of specific cognitive contributions to the EEM effect, given that the EEM effect is known to be influenced by semantic relatedness (Talmi, Luk, et al., 2007; Talmi & McGarry, 2012; Talmi, Schimmack, et al., 2007). Furthermore, the Watts et al. (2014) investigation defined latencies of interest and electrode clusters (to test for laterality and anterior-posterior effects) a-priori, which – although common in ERP research – could limit potential findings, and inflate the type I error rate. Therefore, the current study extends these results by investigating the role of list type on the EEM while controlling for semantic relatedness and employing a less restrained analysis – using statistical parametric mapping (SPM).

4.1.3. Current design and hypotheses

To summarise, the current study investigated the contribution of distinctiveness processing to the encoding of semantically related emotional and neutral stimuli presented in mixed- and pure-lists (where mixed lists represented conditions of distinctiveness processing, and pure lists represented conditions of no distinctiveness processing). EEG was recorded during encoding only. The subsequent memory test was administered after each list using free recall (said to elicit the Dm effect with greater efficacy, Johnson, 1995), before consolidation had occurred but after a

distractor task was implemented (to reduce the contributions of working memory to retrieval, and recency effects).

We hypothesised that behavioural results would replicate previous work, showing an interaction between list type and emotion (MacKay et al., 2004; Schmidt & Saari, 2007; Talmi, Luk, et al., 2007; Talmi & McGarry, 2012; Watts et al., 2014). In the ERP data we hypothesised that, consistent with previous research on memory, a Dm effect would be evident in the P300 and LPP components. Furthermore, we hypothesised that the magnitude of the Dm effect would be greater for emotional than neutral items during the early and late LPP (400-800ms and 800-1500ms) in mixed lists but not pure lists, representing the crucial list type x EEM interaction.

4.2. Method

4.2.1. Participants

Twenty-four participants were recruited using free advertisements and the University of Manchester student credit participation system. Four participants were excluded on the basis of their behavioural performance (too few recalled items per condition), and 4 excluded based on the number of EEG trials per condition (too few trials per condition following pre-processing which involved the removal of some 'bad' trials; see pre-processing details below). The final sample included sixteen participants (6 male, $M = 23$ years, $SD = 4.6$). Participants provided informed consent and were reimbursed for their time and expenses by course participation credits or £15. Ethical approval was obtained from the University of Manchester Research Ethics Committee.

4.2.2. Materials and equipment

Experimental stimuli consisted of 238 colour images (size: 280x210 pixels), half of which conveyed negative valence and were arousing (hereafter referred to as “emotional”), and half of which were neutral in valence and not arousing (hereafter referred to as “neutral”). Of the total images, 14 were practice images (displayed only in the practice block), and 32 were buffer images (16 neutral and 16 emotional); both were excluded from behavioural and EEG analysis. Stimuli were taken from SeRENS (Barnacle, Madan & Talmi, *in prep*); and were supplemented with images taken from the International Affective Picture System (Lang, Bradley & Cuthbert, 1997; 2008). In order to control for semantic relatedness within the neutral set the theme of ‘domesticity’ was chosen. All experimental stimuli contained at least one human being. All stimuli were rated by an independent sample of participants on valence and arousal – using the self-assessment manikin arousal and valence scales (Bradley & Lang, 1994) – and on semantic relatedness (for methods see Barnacle, Madan & Talmi, *in prep*). The emotional and neutral stimuli selected for use in the current experiment were significantly different on measures of arousal, $t(31) = 13.80, p < .001$, Cohen’s $d_z = 2.44$; valence, $t(31) = 15.46, p < .001$, Cohen’s $d_z = 2.73$; and were equated for measures of semantic relatedness, $t(27) = 1.32, p = .20$, Cohen’s $d_z = 0.25$; see Table 4.1 for means and standard deviations of these measures.

Stimuli were allocated to 16 experimental lists: 8 mixed lists and 8 pure lists (4 pure lists of each valence). Mixed lists contained two buffer stimuli (one of each valence, order of presentation randomised) presented at the beginning of each list, and excluded from subsequent analyses to reduce the impact of primacy effects; followed by 12 stimuli – 6 from the emotional and 6 from the neutral sets, in a

randomised order. Pure lists contained two same-valence buffer stimuli followed by 12 same-valence stimuli (either all neutral or all emotional). The allocation of stimuli to list type, the order of lists presented, and the order of stimuli within lists was randomised.

Table 4.1. Statistics relating to ratings of all experimental images

	Neutral		Emotional	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Arousal*	2.34	1.36	5.65	1.41
Valence*	5.34	0.49	2.81	0.66
Semantic Relatedness	5.22	1.31	4.81	1.24

*Mean (M) and standard deviation (SD) statistics from ratings of all experimental images, based on Barnacle, Madan & Talmi, submitted. Arousal scale 1-9: (1=low arousal, 9=high arousal); Valence scale: 1-9 (1=negative, 9=positive); Semantic relatedness scale: 1-7 (1=low relatedness, 7=high relatedness). * indicates measures were significantly different between valence categories.*

4.2.3. Procedure

Our procedure resembled that used by Talmi and McGarry (2012) and Dolcos and Cabeza (2002). Each participant undertook one practice block and sixteen experimental blocks. Each block included three tasks: list encoding, distractor, and free recall (see Figure 4.1). Instructions were presented to the participant for each task on screen, and read aloud by the experimenter at the beginning of the experiment. Participants performed the encoding and distractor tasks alone in the room. Immediately after this, the experimenter re-entered the room in order to record the participant's free recall responses. The participant verbally described each picture they recalled (in any order), whilst the experimenter wrote down their free recall descriptions. EEG was recorded throughout list encoding, but not during distractor and free recall. The experimenter monitored eye movement artefacts in real-time by

observing the continuous EEG data during the recording. Feedback was given to participants if they were not conforming to the instructions to remain still, fixate on the cross and withhold blinks whilst the stimuli were displayed. These instructions were tolerated well by all participants after the practice block.

4.2.3.1. List encoding

In each block participants passively encoded one list of images under intentional encoding instructions. A fixation cross was presented 500ms before each image was displayed and remained on the screen overlaid on the image, which helped to prevent saccadic eye movements (participants were instructed to focus on the fixation and suppress eye movements). Each image was presented for 2000ms (conforming to Dolcos & Cabeza, 2002) with a jittered inter stimulus interval of 4000ms +/- 500ms. This long inter-trial interval was chosen, following Talmi & McGarry (2012), to reduce the effect of potential retrograde amnesia caused by intermixing of neutral and emotional stimuli (Strange, Hurlmann, & Dolan, 2003). Stimuli were displayed on a 15" by 12" sized screen, which was positioned approximately 95cm from the participant. Stimulus presentation and programming was realised using Cogent 2000 (Wellcome Department of Imaging Neuroscience, UCL, UK; http://www.vislab.ucl.ac.uk/cogent_2000.php).

4.2.3.2. Distractor task

After viewing the images participants engaged in an arithmetic task, which aimed to eliminate the contribution of working memory (WM) to the recall output

(complementing the use of buffer images). Two simple sums were presented, one each on the right and left hand side of the screen. Participants were asked to compute the sums mentally and identify the highest value sum by pressing a key relating to the right or the left of the screen ('2' for the left and '3' for the right, using the number keypad on the keyboard). A keyboard placed in front of the participant within comfortable reach allowed the participant to make their selections when prompted. The distractor task lasted for sixty seconds, after which the words 'free recall' were presented on screen.

4.2.3.3. Free recall task

The experimenter re-entered the EEG chamber and asked participants to recall as many images from the previous list as they could remember, in any order and in as much detail as possible. Participants were asked to be specific in their descriptions of stimuli such that descriptions of two similar images should be distinguishable from their responses. Participants were given 3 minutes for this task (recall time determined pro-rata based on the timing of Dolcos & Cabeza, 2002). Participants endured the whole 3 minutes allocated to free recall even if they had stopped actively recalling before this so as to encourage further recall, and to control for differences in motivation levels across participants. In deviation from Talmi & McGarry (2012), the experimenter wrote down the responses as they were spoken by the participant to reduce movement of the EEG head cap.

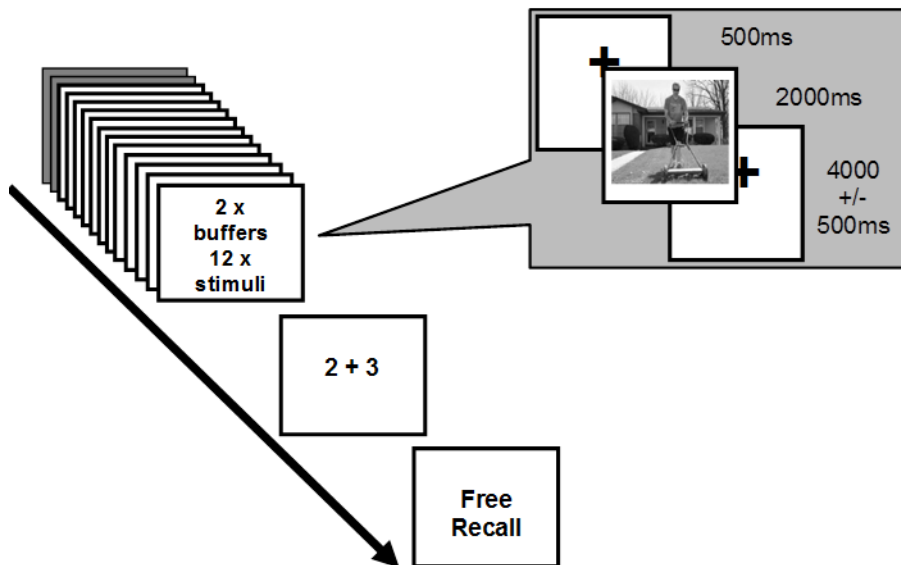


Figure 4.1. Experimental procedure for one block

Participants see a selection of stimuli (white squares, grey indicates buffer stimuli) according to the status of the current block (mixed / pure), followed immediately by a sixty second mathematical distractor task, and finally have three minutes to describe the pictures during free recall. Arrow denotes the progression of time.

4.3. Electroencephalographic recording and reduction

4.3.1. Data collection

BioSemi Active Two measurement system (BioSemi, Amsterdam, www.biosemi.com) was used to measure the electrical signal from the scalp using 64 electrodes and conforming to the 10-20 system embedded in an elasticated cap (Chatrian, Lettich & Nelson, 1998). This system records data reference-free and instead common mode sense (CMS) and driven right leg (DRL) electrodes are used, with no need to reduce impedances before recording (<http://www.biosemi.com/faq/cms&drl.htm>; e.g. Roberts, Tsivilis, & Mayes, 2013; Weinberg & Hajcak, 2010). Additional electrodes were used for detecting eye artefacts: two electrodes for vertical electrooculogram movements (EOG), two for horizontal EOG, and two for subsequent re-referencing attached at the right and left mastoids. The EEG signal was recorded using ActiView

software, which applies a 0.16Hz on-line highpass filter and a 100Hz on-line lowpass filter.

4.3.2. EEG pre-processing

EEG data was pre-processed and analysed using SPM8 for MATLAB (Litvak et al., 2011). The data was re-referenced offline to the combined mastoids reference, which is said to optimise LPP effects (Hajcak, Weinberg, Macnamara & Foti, 2012) and a low-pass filter was applied to remove frequencies above 40Hz from the continuous data (in line with previous studies e.g. Jaeger, Johnson, Corona, & Rugg, 2009; Roberts et al., 2013; Weymar, Bradley, Hamm, & Lang, 2012; Weymar, Löw, & Hamm, 2011; Weymar, Löw, Melzig, & Hamm, 2009; Weymar et al., 2010). Data were then downsampled from 2048Hz to 125Hz and epoched from -200ms pre-stimulus to 1500ms post-stimulus presentation, a time window selected on the basis of previous work (Dolcos & Cabeza, 2002; Melzig, Hamm, Weymar, & Löw, 2009; Weymar et al., 2010). A combination of methods were utilised to remove artefacts from the data. Firstly, individual participant's eyeblinks were identified in their continuous data, and an epoch identified from -500ms to +500ms relative to the peak of the blink. An average of the eyeblink topography (using 1 component) per participant was then created using the singular value decomposition (SVD) method, and this data was then removed from the epoched EEG using the signal source projection method (SSP, Nolte & Hämäläinen, 2001). The second stage of artefact correction was to apply a threshold of 120mV (as per Schaefer et al., 2011), whereby any trials with an amplitude exceeding this threshold were removed from further analysis. In addition to this, any electrode with greater than 20% rejected trials was marked as a 'bad' channel.

Remaining trials were then averaged according to their condition using the robust averaging algorithm (Litvak et al., 2010). This method considers the distribution of values over trials for each channel and time point, and the outliers are down-weighted when computing the average. Finally a low-pass filter was re-applied at 40Hz (to remove any noise introduced from the process of robust averaging) followed by baseline correction between -200ms and 0ms time-locked to stimulus onset. Following this pre-processing procedure, contrasts were generated with the resultant data files, which were then averaged across participants for the purpose of visualising and comparing condition specific ERPs³.

4.4. Analysis

4.4.1. Behavioural analysis

Free recall responses were scored following previous work (Bradley, Greenwald, Petry, & Lang, 1992; Talmi & McGarry, 2012). The experimenter matched the participant's free recall descriptions to the experimental stimuli seen in that block. Recall responses were coded by a second independent coder, and agreement amongst coders was high (97%). Disagreements were resolved through discussion.

For the dependent variable in behavioural analyses we used a proportion score - the number of correctly recalled items in a given condition divided by the total number of items of that kind seen in that condition.

³ We additionally applied a low-pass filter of 20Hz to these ERPs for the purposes of presentation only.

4.4.2. EEG analysis

To make inferences about the effects of distinctiveness processing and valence on subsequent memory, statistical parametric mapping (SPM12) was used (Litvak et al., 2011). Analysis of EEG data using SPM takes the trial-averaged ERP data per subject, electrode, and condition, and converts this using interpolation into three dimensional images consisting of a 64 x 64 pixel grid, (pixel size 2.13 x 2.69mm) with time in milliseconds as the third dimension. As part of this conversion process, missing data from any 'bad' channel was replaced with interpolated data from surrounding electrodes, so as to be included in subsequent analysis. These images were smoothed with a [8 8 8] smoothing kernel (where the first two parameters relate to space, and the third parameter relates to time). To ensure a reliable estimation of electrophysiological response in each condition, a minimum of 10 artefact-free trials per condition was set as the inclusion criteria for accepting any participant's data for analysis. On average participants contributed 20.4 trials per condition (mixed emotional recalled=25.2; mixed emotional forgotten=16.1; mixed neutral recalled=17.9; mixed neutral forgotten=23.2; pure emotional recalled=23.8; pure emotional forgotten=17.6; pure neutral recalled=21.3; pure neutral forgotten=18.4). The lowest accepted number of trials per condition was 11; however, this was only the case for one condition and one participant; and on average, participants had a greater number of trials than this per condition (as per the averages reported above). Although we recognise that this number of trials is relatively low, data has shown that reliable and robust ERPs of emotional and neutral processing can be obtained with as few as 8 trials per condition (Moran, Jendrusina, & Moser, 2013). Despite this

evidence, we acknowledge that a greater reliability and accuracy would be afforded by data with a greater number of accepted trials per condition.

This method of analysis was preferable compared to other alternatives which may group electrodes and compare average amplitudes per condition within discrete sub-epochs. This is particularly unhelpful when investigating effects such as the LPP which is characterised by a sustained, broad topographical distribution (Hajcak et al., 2012). To counter these challenges, SPM prevents the need for a-priori topographical- and latency-of-interest definitions, allowing a full interrogation of all data collected; and thus reducing the possibility of type I and type II errors. One noteworthy difference in using SPM to analyse these data, is that unlike taking an average amplitude per condition in a pre-defined epoch (e.g. 100-200ms), SPM considers significance at the lowest possible temporal resolution determined by the smoothing kernel applied; which for this study means that any significant difference between conditions which lasts longer than 8ms will be identified in the results. Of course a duration of significance of 8ms is not likely to represent a true difference between conditions; and therefore, as well as controlling for multiple comparisons (see below) we excluded any results with a duration of significance less than 30ms.

In order to define appropriate parameters to determine significance and to control for multiple comparisons, a Monte Carlo simulation was conducted using REST AlphaSim in MATLAB (Song et al., 2011). This method determines the required minimum number of contiguous pixels (or voxels in 3D images) required to identify true regions of significant activity when used in combination with a specified cluster forming threshold, whilst taking into account smoothness of the data (using SPM.xVol.FWHM). It is assumed that whereas true activation is likely to form clusters, noise by definition should be random and therefore not form clusters; thus cluster

size can (in part) distinguish signal from noise. Using 1000 iterations of the Monte Carlo simulation we determined that an uncorrected cluster forming threshold of $p < 0.05$ and a cluster size of $k_E = 753$ (contiguous pixels) corresponded to a family wise error (FWE) whole brain corrected value of (FWE) $p < 0.05$ when analysis is conducted on data from 0 – 1500ms post-stimulus (Ward, 2000). These experiment-specific combined significance criteria were therefore applied in all statistical testing of our EEG data.

4.5. Results

4.5.1. Behavioural results

Using proportion recalled as the dependent variable, results of the 2 (list type: pure/mixed) x 2 (valence: negative/neutral) repeated measures ANOVA identified a significant main effect of valence ($F(1, 15) = 14.16, p = .002, \eta_p^2 = .49$). The main effect of distinctiveness was not significant ($p = .20$). As expected, there was a significant distinctiveness x valence interaction $F(1, 15) = 18.07, p = .001, \eta_p^2 = .55$. Post-hoc Tukey HSD t-tests were used to unpack these results whilst controlling for multiple comparisons. This method revealed – as expected – that EEM was only found in mixed lists ($t(15) = 4.84, p < .001, d_z = 1.89$); not pure ($t(15) = 1.13, p = .28, d_z = .42$) (see Figure 4.2). Significantly fewer neutral items were remembered in mixed compared to pure lists ($t(15) = -3.46, p = .003, d_z = 1.10$), and there was no significant difference between negative items recalled in mixed compared to pure lists ($t(15) = 1.78, p = .095, d_z = .54$).

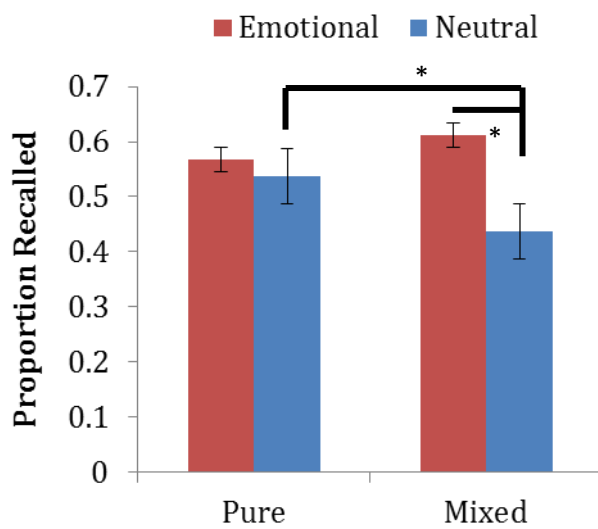


Figure 4.2. Proportion Recalled Scores

*Average proportion recalled items in pure and mixed conditions for emotional and neutral stimuli. Error bars indicate standard deviation. * indicates $p < .05$.*

4.5.2. EEG results

The eight three dimensional images for all conditions (according to the factors and levels – list type: pure vs. mixed; valence: emotional vs. neutral; and memory: recalled vs. forgotten) per participant were entered into a 4-level flexible factorial ANOVA (as if the dependent variable) using SPM12 in MATLAB. For conciseness we report the location (x and y coordinates in mm), Z score, and duration (milliseconds [ms] post-stimulus onset) for the most significant peak of activation from each significant cluster only.

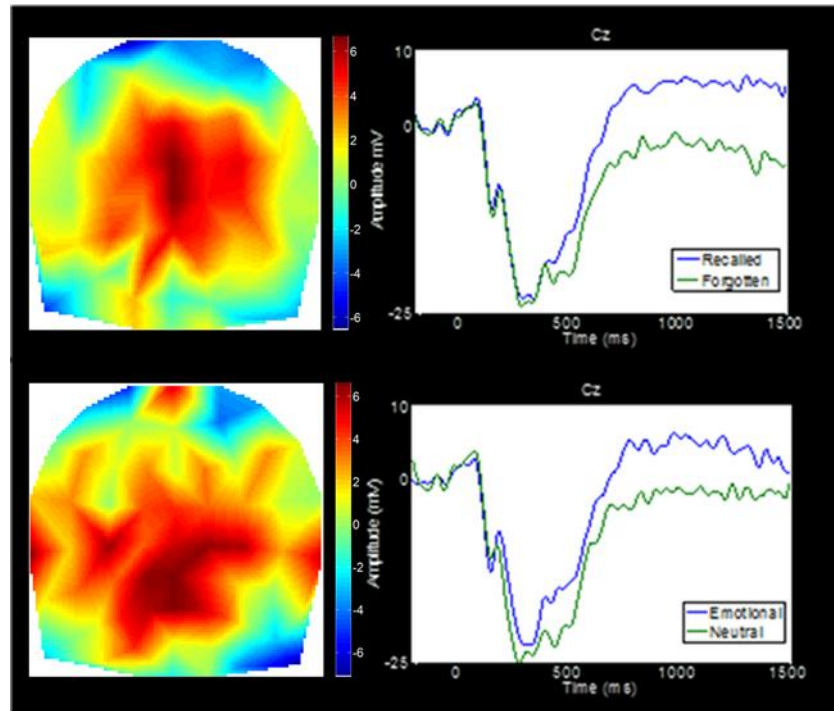


Figure 4.3. Scalp topographies and ERPs for the main effects of memory and emotion

Scalp topographies (left) as viewed from the top of the head, are time averaged for the duration of significance (see results), and display the amplitude difference between recalled and forgotten, and emotional and neutral (top and bottom plots respectively). ERPs (right) are taken from electrode Cz, where significance was common in both contrasts. A 20Hz low-pass filter was applied for display purposes only. mV = microvolts.

4.5.2.1. Main Effects

We first wanted to verify that our data replicated the main effects of memory and emotion from the literature. For the main effect of memory [recalled > forgotten] we identified four significant spatially overlapping clusters with peak activations at midline and midline-adjacent locations. The nearest suprathreshold channels were AFz (peak $x = 0, y = 42; Z = 2.97; k_E = 838$), F1 (peak $x = -6, y = 21; Z = 4.32; k_E = 39770$), FCz (peak $x = 0, y = 5; Z = 2.91; k_E = 3174$), and CP2 (peak $x = 17, y = -30; Z = 3.23; k_E = 5151$) with overlapping temporal significance ranging from 316ms until 1398ms (see figure 4.3, top).

For the main effect of emotion [emotion > neutral] we identified one significant cluster with a broad scalp topography which centred around midline and central-midline scalp locations (nearest suprathreshold channel FC2). This cluster (peak $x = 13, y = 8; Z = 6.73; k_E = 313147$) was significant from 219ms – 1458ms (see figure 4.3, bottom).

4.5.2.2. Interaction Effects

We first sought to examine electrophysiological correlates relating to memory effects as identified in the behavioural results: Greater memory for mixed compared to pure emotional stimuli (although not statistically significant in the behavioural data), and greater memory for pure compared to mixed neutral stimuli (which was statistically significant in the behavioural data). Essentially, this analysis highlights how processing of a given stimulus is different according to list type – an integral part of the argument for a list type dependent distinctiveness processing state.

Firstly a t-test was conducted which compared the electrophysiological correlates of successful emotional encoding in mixed compared to pure lists, using an inclusive mask of the main effect of memory (recalled>forgotten). Results identified 4 significant clusters with considerable spatial and temporal overlap, at midline and central-right scalp sites. We identified a significant cluster for which the peak was located at nearest suprathreshold site C2 (peak $x = 11, y = -11; Z = 3.20; k_E = 2826$) beginning at 621ms and extending to the end of the epoch (1500ms). Two spatially and temporally overlapping clusters were also identified; one with a shorter duration of significance (629ms – 690ms) was identified at nearest suprathreshold scalp site CPz (peak $x = 0, y = -36; Z = 2.87; k_E = 2970$); and another at C4 significant from

632ms – 1286ms (peak $x = 34, y = -14; Z = 3.43; k_E = 6936$). The final significant cluster was identified later in the epoch, from 1037ms – 1500ms at Fz (peak $x = -4, y = 21; Z = 3.25; k_E = 885$).

For the neutral items a t-test was conducted to compare the electrophysiological correlates of successful neutral encoding in mixed compared to pure lists, using an inclusive mask of the main effect of memory (recalled>forgotten). Four significant clusters were identified, with a broad central-midline topography. We identified a significant cluster for which the peak was located at nearest suprathreshold scalp site FCz between 278ms and 610ms (peak $x = 4, y = -1; Z = 4.09; k_E = 3629$); followed by a significant cluster at CP4 between 422ms and 674ms (peak $x = 28, y = -46; Z = 2.84; k_E = 2902$). Later in the epoch we found two spatially overlapping clusters at sites FC1 and FC2 between 681ms – 728ms, and 946ms – 1320ms respectively (FC1 peak $x = -11, y = -3; Z = 3.18; k_E = 2323$; FC2 peak $x = 9, y = 2; Z = 3.86; k_E = 6394$).

Next, mirroring the two-way interaction between the effects of list type and valence on proportion recalled in the behavioural data, we tested the crucial three-way interaction between list type, valence, and memory. This analysis asked where the difference in electrophysiological activity between recalled and forgotten events was greater for emotional compared to neutral stimuli, and where this difference was greater in mixed compared to pure lists. To unpick these results we also investigated the three way results for significant Dm effects of each condition (mixed emotional Dm, mixed neutral Dm, pure emotional Dm, pure neutral Dm), and inverse Dm effects (forgotten > recalled for each condition) to see what was driving this interaction. We achieved this by testing each Dm contrast, masked by the three way interaction.

The three way interaction analysis identified 3 significant clusters. Firstly, we identified a significant cluster at nearest suprathreshold site C4 (peak $x = 32, y = -19$; $Z = 2.45$; $k_E = 1085$) between 269ms and 451ms. Using the masking strategy outlined above we found that the significance at this peak was driven by a significant inverse mixed neutral Dm. Next, a significant cluster was identified at nearest suprathreshold site FC2 (peak $x = 19, y = 8$; $Z = 3.79$; $k_E = 9268$) between 271ms and 398ms, which overlapped spatially and temporally with the cluster at C4 (reported above). Using the same masking procedure, we found that the significant effect in this peak was driven by a significant mixed emotional Dm effect, and a significant pure neutral Dm effect; in addition to a significant inverse mixed neutral Dm effect. Finally, the largest significant cluster was identified at nearest suprathreshold scalp site Fz between 893ms and 1500ms (peak $x = -4, y = 21$; $Z = 4.70$; $k_E = 101477$). Using the same masking procedure we identified that the significance at this peak was again driven by a significant mixed emotional Dm, and a significant pure neutral Dm; in addition to a significant inverse mixed neutral Dm. See Figure 4.4 for the Dm contrast topographies and contrast estimates relating to this analysis, taken from the nearest suprathreshold electrodes. N.B. the direction of Dm effects presented in Figure 4.4 represents data extracted from specific electrodes, and therefore may not correspond to the direction of effects reported above (Dm, and inverse Dm), as those reported above could be located more strongly at a different location within the significant cluster.

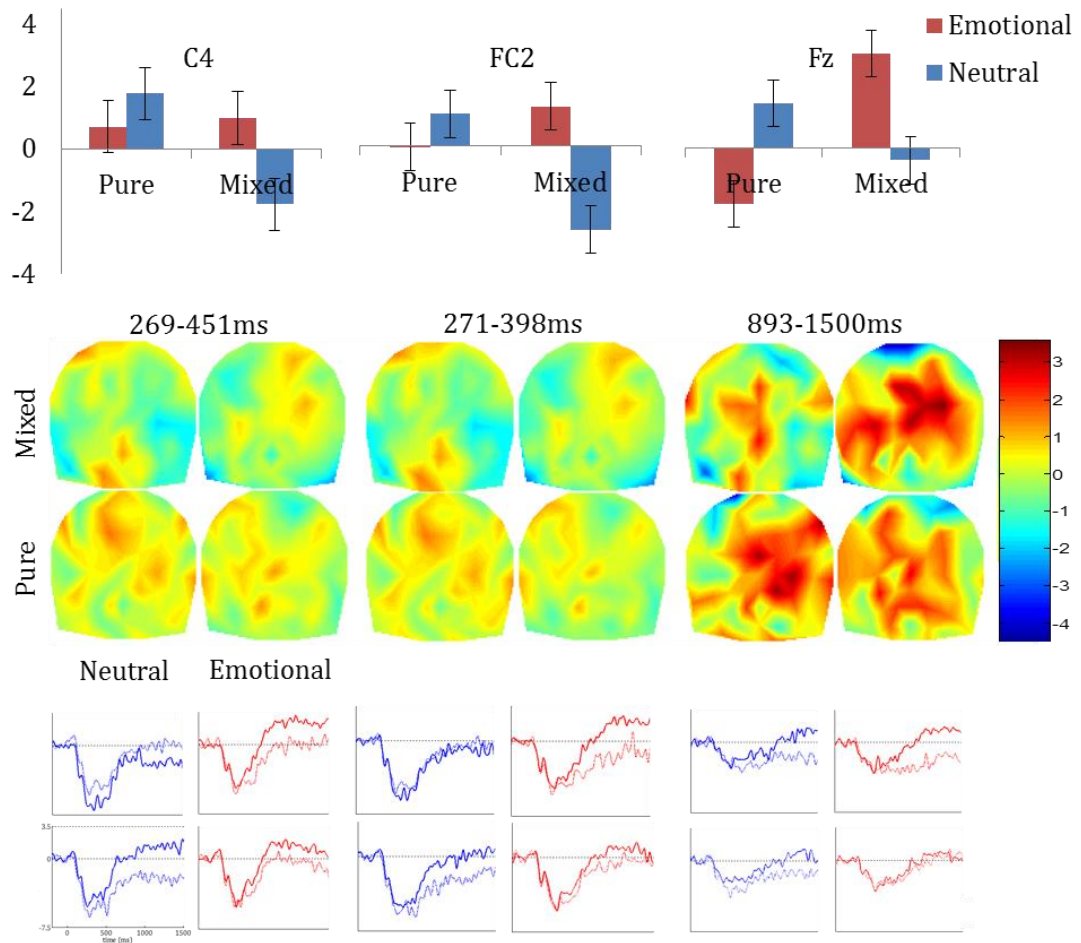


Figure 4.3. Interaction Effects Results

Top: Plots showing contrast estimates of each Dm contrast (recalled - forgotten) for the factors List type, and Valence; extracted from the nearest suprathreshold electrode sites to the peaks of significance in the interaction analysis (C4, FC2, and Fz; left to right). Contrast estimates represent data at the peak latency of significance, not averaged across time. Bars show 90% confidence intervals, confidence intervals overlapping '0' of the y axis denote no significant Dm in that condition.

Middle: Scalp topography maps (top view) of each Dm contrast, time averaged across the temporal significance identified in the interaction analysis (respective temporal significance detailed above topography plots). Legend provided at right; warm colours (positive) indicate recalled > forgotten, whereas cool colours (negative) indicate forgotten > recalled.

Bottom: ERPs for recalled (solid line) and forgotten (dashed line) trials according to list type and valence (red = emotional, blue = neutral) extracted from nearest suprathreshold electrode sites. ERPs by condition organised as per scalp topographies above. X axis denotes epoch of interest from -200ms to 1500ms. Y axis denotes amplitude in microvolts (mV) from -7.5mV to 3.5mV; positivity plotted upwards; dashed grey line dissecting the y axis denotes 0mV.

4.6. Discussion

4.6.1. Interpretation of behavioural results

Consistent with our hypotheses, the behavioural results replicated those of Talmi and McGarry (2012) and others that have shown the behavioural EEM effect at short encoding-test delays, i.e. < 20 mins (Bradley, Greenwald, Petry and Lang, 1992; Hamann, Ely, Grafton, & Kilts, 1999; Ritchey, Dolcos, & Cabeza, 2008; Tabert et al., 2001; Palomba et al., 1997; Watts et al., 2014). Importantly, this adds to the evidence demonstrating that EEM may indeed occur before consolidation, a finding currently not explained by the modulation model (McGaugh, 2004). Consistent with previous results (Sommer et al., 2008; Talmi & Moscovitch, 2004), using semantically related stimuli resulted in no behavioural EEM in pure lists. This demonstrates the importance of using semantically related stimuli, given that non-semantically related stimuli do show the EEM effect in pure lists (e.g. Watts et al., 2014). In addition to these expected EEM effects, when controlling for semantic relatedness the behavioural results also evidence the modulatory role of list type in EEM. When items are presented in mixed lists of emotional and neutral stimuli (said to invoke distinctiveness processing) a significant EEM effect is observed, driven by a decrease in memory for neutral items relative to the pure condition. This suggests that distinctiveness processing is detrimental for the encoding of neutral items (replicating Watts et al., 2014). When considered alongside Mather & Sutherland's (2011) ABC theory these findings are consistent with the suggestion that arousal creates competition for processing resources.

4.6.2. Towards an electrophysiological mechanism of the EEM

Beyond the behavioural results, as hypothesised, our ERP results reveal a significant effect of subsequent memory with electrophysiological activity associated with subsequently recalled items greater than activity associated with subsequently forgotten items in the P300 and LPP components; consistent with previous findings (Fabiani & Donchin, 1995; Gutchess, Ieueji, & Federmeier, 2007; Kaestner & Polich, 2011; Melzig et al., 2009; Wagner, Koutstaal, & Schacter, 1999). We also found the expected emotion effect – greater amplitude ERPs for the encoding of emotional compared to neutral items in the time window of the LPP component (Dolcos & Cabeza, 2002; Olofsson et al., 2008). Replicating these fundamental results confirms the basic integrity of the data collection, pre-processing and analysis.

Interaction analyses between list type and memory, separately for emotional and neutral stimuli, evidenced that the encoding of a given stimulus differs significantly according to the type of list – mixed or pure. This provides evidence of specialised list type encoding mechanisms, of which the mixed list mechanism may be termed the distinctiveness processing mechanism. To understand how these mechanisms contributed to differences in the EEM effect, interpretation of the three way interaction analyses is essential.

Results of the three way interaction (list type x valence x memory) afford us a rich description of the electrophysiological activity underlying the contribution of cognition at encoding to the EEM effect, the potential mechanism of which we discuss below. Although in using SPM we did not define a-priori temporal or spatial regions for this analysis as previously (Watts et al., 2014) we can still compare the current results to other findings in the literature (Dillon, Cooper, Grent t-Jong, Woldorff, &

LaBar, 2006; Dolcos & Cabeza, 2002; Kiefer et al., 2007; Palomba et al., 1997). Effects that contributed to the three way interaction began at 269ms post-stimulus onset, with a peak of significance at nearest electrode C4, which were driven by a significant inverse mixed neutral Dm. The morphology of this result is consistent with a P3 attention effect (Ferrari, Bradley, Codisotti, & Lang, 2010; Polich, 2007; Watts et al., 2014), which suggests that attentional processing for mixed neutral items is deficient early in stimulus encoding processes. However, it is acknowledged that as we did not manipulate attention this conclusion relies somewhat on reverse inference, and as such is stated with caution. This finding provides us with information regarding the mechanism of EEM and the contribution of distinctiveness processing: early *neutral* (but not emotional) encoding (from 269ms) is modulated by list type in this cluster. Our findings from this early cluster are broadly consistent with the results of analysis from the 200-400ms window from Watts et al. (2014), in which a cancelled mixed neutral Dm effect (no significant difference between recalled and forgotten ERPs) was found in posterior electrode sites. Although the specificity of the current results are necessarily different due to the difference in analytical approach adopted (also see detailed methodological discussion below), we believe that the current results are broadly consistent with the previous findings (Watts et al., 2014).

A further significant cluster which was spatially and temporally overlapping with that of the above was identified from 271ms with its peak identified as closest to electrode FC2. The results demonstrate that for this cluster, we see a mirroring of the effect in the earlier cluster (described above), with the addition of a significant mixed emotional Dm and pure neutral Dm. For the C4 cluster (outlined above) we can see that neutral items in mixed lists are lacking in attentional resources, however, results from the C4 cluster present no evidence as to what dominates the attentional

resources causing this deficit for neutral items. At the FC2 cluster we see that in addition to a significant inverse mixed neutral Dm, a significant mixed emotional Dm is also present. This could suggest that attentional resources are diverted from neutral to emotional items in mixed lists at an early stage of processing, and that this preferential attentional processing for emotional items is represented by a change in topography – more frontal for emotional attention. We believe that this potential early differential allocation of attentional resources may be driven by the inherent salience of the emotional items compared to neutral (Bradley, Codisotti, Cuthbert, & Lang, 2001); an interpretation consistent with accounts of eye-witness testimony (e.g. Christianson, 1992); and supported by evidence that attention to emotional items is reduced less so than attention to neutral items under conditions of divided attention (Pottage & Schaefer, 2012; Talmi, Schimmack, Paterson, & Moscovitch, 2007). Furthermore, research has also found that when the duration of exposure and eye fixations for emotional versus neutral stimuli are controlled, emotional items were still better remembered (Christianson, Loftus, Hoffman, & Loftus, 1991); a pattern also observed under instructions of directed forgetting (Bailey & Chapman, 2012), demonstrating the irrevocable salience of these items.

The significance of the late cluster began at 893ms at nearest electrode Fz and represents a further step in the electrophysiological mechanism of cognitive contributions to the EEM. In accordance with our hypotheses, the mixed emotional Dm was significant, whereas we found only a significant inverse Dm effect for mixed neutral stimuli (consistent with Watts et al., 2014). The morphology of these effects is consistent with LPP effects (Dolcos & Cabeza, 2002; Hajcak & Nieuwenhuis, 2006; Righi et al., 2012; Weinberg & Hajcak, 2010) relating to working memory and the manipulation of stimuli in working memory (Azizian & Polich, 2007); which is

especially noted in the investigation of emotionally arousing stimuli (Leutgeb, Schäfer, & Schienle, 2009), and which replicate the effects of the analysis in the epoch of 800-1500ms from Watts et al., 2014. Echoing the patterns of our interpretation of attention effects in our earlier findings, we propose that in mixed lists working memory and stimulus manipulation resources are allocated to emotional items, which detracts from the available resources for the neutral items (again consistent with ABC theory; Mather & Sutherland, 2011). There are (at least) two plausible explanations of how mixed list emotional items are identified as targets of working memory. Firstly, it may be that mixed list emotional items are selected for the attribution of working memory resources based on their having already received extra attention earlier in encoding (from 271ms). Alternatively, working memory allocation may be dependent on an attention-based assessment of the item: stimuli which receive more attention are more accurately assessed as requiring further working memory resources (or not), compared to those stimuli which are less well attended to.

From our three way interaction analysis of the ERP data, we identified significant Dm effects for pure neutral but not pure emotional stimuli. It is notable that the significant pure neutral Dm effects did not correlate with an advantage for the recall of pure neutral compared to emotional items. These results suggest that neutral items make use of attentional and working memory resources in pure lists, processes that our data would suggest are not necessary for the pure emotional items (no significant pure emotional P300 or LPP effects), which are recalled equally as well as neutral items without this processing. There are at least two plausible explanations for this EEG-behaviour discrepancy: either there exists a disturbance to processing of these pure neutral items at later stages of item processing, (e.g. at storage, or

retrieval) damaging the potential mnemonic benefit of this extra processing; or that in order for pure neutral recall performance to be equal to pure emotional recall performance, participants simply required more attentional and working memory / stimulus manipulation resources. To consider the latter suggestion in more detail, we could suggest this to be plausible given that neutral pictures convey no obvious salience or personal significance (e.g. Bradley, Codispoti, Cuthbert, & Lang, 2001), and therefore as a group, these items are already disadvantaged in processing for subsequent memory. In order to 'boost' performance for these already disadvantaged items we need to employ greater levels of processing, which reconcile the inherent differences in salience compared to the emotional items; and which may ultimately contribute to the equal memory for these two kinds of stimuli in pure lists.

In addition to working memory, the LPP has also been associated with motivational relevance (e.g. Lang & Bradley, 2010; Bradley, Hamby, Low, & Lang, 2007) which may explain the difference in this component between the pure and mixed emotional memory. Under this assumption, a plausible interpretation would be that compared to pure list conditions, during mixed lists the motivational relevance of emotional items is greater (consistent with ABC theory, Mather & Sutherland, 2011). If the motivational relevance of emotional items in mixed lists is greater than in pure lists regardless of the fact that properties of the emotional stimuli remain the same in both types of list; this suggests that item processing does not occur in a trial-by-trial manner. Rather it seems to be influenced by the list composition and the processing required to navigate this kind of list encoding environment – i.e. differential processing under distinctiveness processing (mixed-) compared to no-distinctiveness processing (pure-list) conditions. This is plausible given that participants receive a message at the beginning of the encoding list which informs them about the nature of

the encoding list to come (all emotional, all neutral, or a mixture of emotional and neutral pictures); which may serve as a cue to employ a list-specific processing strategy. Given these findings, we suggest that the encoding list acts as a temporally bound episode in which the processing of a given trial is influenced by ongoing list-long processing strategies such as distinctiveness processing. This conclusion is supported by neuroimaging data which demonstrates a significant contribution of state-related activity to encoding success, associated with discrete *sets* of encoding and is unrelated to the encoding of *individual* items (e.g. Fernández, Brewer, Zhao, Glover, & Gabrieli, 1999; Otten, Henson, & Rugg, 2002; Otten & Rugg, 2001; Rugg, Otten, & Henson, 2002). Although not tested here, it's also worth mentioning the contribution of other states which have been shown to contribute to subsequent successful memory such as mood state (Kiefer et al., 2007; Padovani, Koenig, Brandeis, & Perrig, 2011), and retrieval state (e.g. Düzel et al., 1999) which may also play a role here.

Taken together our findings suggest a mechanism for the contribution of distinctiveness processing to the EEM. Early in encoding emotional and neutral stimuli are differentiated; and importantly, are differentially processed according to the composition of the list. In pure lists, neutral items receive more working memory resources compared to their pure emotional counterparts. However, given that this does not represent an advantage to memory (pure neutral memory is statistically equivalent to pure emotional memory), we suggest that this extra processing is required to compensate for the lack of salience of neutral items compared to emotional items. In mixed lists, emotional stimuli detract attentional and working memory resources from neutral stimuli, a pattern not observed in pure lists. This supports our hypothesis that an ongoing distinctiveness processing state contributes

to the mixed EEM. As we observed the same pattern of significance for the early attention components and the later working memory components in mixed lists, this positions attention as a potential gatekeeper to working memory and stimulus manipulation resources allocation, a pattern predictive of subsequent memory. However, this investigation cannot determine whether these two factors are independently sufficient and necessary for subsequent memory, whether one leads to another, or whether both are required and instigated independently.

Ultimately, these results suggest that in mixed list conditions, an ongoing processing state that we term distinctiveness processing, is embodied by the list-long readiness to assess and allocate attentional and working memory resources; and that this state of changeable processing is beneficial for subsequent emotional memory, and detrimental for subsequent neutral memory. Although our results are largely consistent with ABC theory (Mather & Sutherland, 2011), the current data cannot verify that the differential allocation of resources was initiated by arousal, or indeed that emotional and neutral stimuli directly competed for resources.

4.6.3. General evaluation

With regards to the design of this study, it is important to acknowledge that this study isolates a very specific component of EEM – the contribution of distinctiveness processing as operationalised through the manipulation of list type while controlling semantic relatedness. Although our previous work suggested that neutral stimuli played an important role in the EEM effect (Watts et al., 2014), the stimuli in that experiment were not controlled for semantic relatedness. As research has demonstrated that EEM is part explained by between-set differences in semantic

relatedness driven by greater within-set semantic relatedness for emotional compared to neutral stimuli (Buchanan et al., 2006; Talmi, 2013), controlling this factor in the current design has removed an important confound. However, by the very nature of the importance of semantic relatedness contributions to the EEM in an uncontrolled environment (i.e. outside the laboratory), it should be considered that by removing such a confound one also potentially reduces an important part of the mnemonic strategy that naturally contributes to the EEM. Consequently, the results of our experiment should be interpreted as demonstrating the contribution of distinctiveness processing (without semantic relatedness) to the immediate EEM, a very specific aim. In light of this, future studies wishing to investigate the cognitive contributions to the immediate EEM effect could use a variety of more- and less- semantically related stimuli; and use semantic relatedness ratings from participants as a covariate in the analysis model to orthogonalise – but not remove – the effect of semantic relatedness.

There are two important points to note about the difference between our current findings and that of our earlier work (and that of others), which may be explained in light of methodological differences (analysis by SPM as here, versus data extraction and averaging). Firstly, whereas Watts et al., (2014) reported a cancelled Dm effect (i.e. recalled and forgotten activity was equivalent) in the mixed neutral condition, the current results furthermore suggest a significant inverse mixed neutral Dm effect. It is possible that the process of averaging ERP amplitudes over a protracted time period (e.g. 200-400ms) as in Watts et al., (2014) meant that this effect was not borne out statistically, whereas the current method allowed us greater specificity to investigate effects with a shorter duration. Secondly, the significant inverse mixed neutral Dm that we identified as part of the interaction effect peaked at

electrode C4, which is different to the posterior site identified in Watts et al., 2014. However, this is the peak of a relatively large topography which, as seen in Figure 4.4, spans right-lateral midline and right-posterior sites. In Watts et al., (2014) laterality and anterior-posterior effects were investigated by grouping six electrodes together (note, none of these electrode groups included electrode C4). These differences in analysis adds a level of difficulty in comparing the results directly, however we argue that they are broadly consistent based on their general similarities in topography and direction of significance.

4.7. Conclusion and future directions

In conclusion, the current study has supported existing literature by evidencing the existence of an immediate EEM (Bradley, Greenwald, Petry and Lang, 1992; Hamann, Ely, Grafton, & Kilts, 1999; Ritchey, Dolcos, & Cabeza, 2008; Tabert et al., 2001; Palomba et al., 1997; Watts et al., 2014). Furthermore, we have added to this literature by isolating the electrophysiological correlates of the contribution of what we term distinctiveness processing to the EEM. Highlighting the existence and importance of the contribution of cognitive factors such as distinctiveness processing to the EEM will aid the understanding of the process of EEM as a whole, and also may have application outside of the laboratory. For example, this could have implications for the treatment of people whose experience of emotional events prove to be subsequently problematic – e.g. in post-traumatic stress syndrome (PTSD, Lanius et al., 2003; Parsons & Ressler, 2013; Tapia, Clarys, Bugajska, & El-Hage, 2012), for example in the development of novel targeted cognitive therapies.

As our results successfully identified electrophysiological evidence of an interaction between list type and EEM at encoding, it would be pertinent next to investigate this effect using a modality with greater spatial resolution, such as fMRI. This has the potential to add to the current literature by further elucidating the neural mechanism which drives this effect to include the relevant brain structures and their interactions. Finally, it will be necessary to discern whether the influence of distinctiveness processing contributes to subsequent memory when tested immediately (as in this experiment) *and* additionally after a delay. This could help to disentangle whether cognitive factors such as distinctiveness processing contribute only with a short-acting effect, or whether they also continue to contribute to EEM when measured after consolidation.

5. Using fMRI to investigate the contribution of distinctiveness processing to the immediate emotional enhancement of memory

Abstract

Behavioural evidence suggests that cognitive factors play a role in the emotional enhancement of memory (EEM); however more neural evidence is required to support this notion. We tested free recall memory of emotional and neutral scenes using a subsequent memory paradigm to isolate fMRI BOLD correlates of successful stimulus encoding. Stimuli were controlled for semantic relatedness and presented in different list types: pure lists (emotional *or* neutral); or mixed lists (both): during which prior research suggests that distinctiveness processing occurs. Distinctiveness processing is the sustained cognitive effort applied during encoding in light of stimuli with changing properties. Replicating previous results, a behavioural EEM was found in mixed but not pure lists. Neural evidence identified different areas of activation associated with successful memory of emotional and neutral scenes (anterior hippocampus and posterior parahippocampus respectively), and encoding elicited differential activation according to list type irrespective of valence. This provides novel evidence of a neural basis for list type dependent encoding mechanisms, data which may help to characterise distinctiveness processing in mixed lists. The results of a three way interaction analysis (list type x valence x memory) found that activation in the supramarginal gyrus (SMG) and superior temporal gyrus (STG) contributed to successful mixed emotional memory greater than all other conditions; and SMG activity correlated linearly with the behavioural EEM effect. Based on these findings we propose that reflexive reorienting and semantic processing are among the crucial psychological processes of the EEM effect. A potential neural model of the EEM including the contributory cognitive factors unveiled by this investigation is discussed.

5.1. Introduction

The Emotional Enhancement of Memory effect (EEM) refers to the better memory of emotional compared to neutral information or events, and is well characterised in the neuroimaging literature. In particular, McGaugh's modulation model (McGaugh, 2004, 2013) has amassed a wealth of supporting evidence demonstrating that the amygdala (AMY) modulates the activity of the hippocampus (HPC) via adrenal stress hormones and glucocorticoids, producing a memorial benefit to emotional items compared to neutral items following the process of consolidation (e.g. *in animals*: McIntyre, Hatfield, & McGaugh, 2002; McReynolds et al., 2010; Roozendaal, Portillo-marquez, & McGaugh, 1996; *in humans*: Cahill et al., 1996; Dolcos, Labar, & Cabeza, 2004; Schwarze, Bingel, & Sommer, 2012; *for reviews see* Hermans et al., 2014; McGaugh, 2004; McIntyre, McGaugh, & Williams, 2012; McReynolds & McIntyre, 2012). In parallel to this an emerging body of research seeks to explain the correlates of the EEM as it is evident *before* consolidation (the so called "immediate EEM effect", before synaptic consolidation has been 'completed' – see Alberini & Kandel, 2015), particularly focussing on cognitive factors at encoding and retrieval as mediators of this effect (mediation theory; Talmi, 2013).

5.1.1. Cognitive contributions to the immediate EEM

This growing area of research has already demonstrated convincing results regarding the contribution of several cognitive factors to the immediate EEM effect, for example – attention and semantic relatedness (Talmi & Moscovitch, 2004; Talmi, Schimmack, Paterson, & Moscovitch, 2007; Talmi et al., 2013). This research demonstrates that

the immediate EEM effect can be abolished when memory for emotional and neutral items is tested separately (in “pure lists” of only emotional or only neutral stimuli) and if the semantic relatedness of neutral items is increased to equal that of emotional items (which are typically higher in semantic relatedness, the thematic grouping of stimuli). However, equivalent semantic relatedness does not abolish the EEM when emotional and neutral items are encoded and tested together (i.e. when stimuli are randomly intermixed, “mixed lists”); suggesting that another contributory factor exists. Attention would seem a likely candidate to explain this immediate EEM effect, however mediation analysis has shown that extra attention to emotional stimuli does not fully account for the EEM (Experiment 1, Talmi & McGarry, 2012).

In fact the list type itself (pure versus mixed) has been noted as an important factor in the immediate EEM effect (Nguyen & McDaniel, 2014; Talmi, Luk, McGarry, & Moscovitch, 2007; Talmi & McGarry, 2012). Mediation theory (Talmi, 2013) suggests that the cognitive factor – distinctiveness processing – said to occur in mixed lists (therefore associated with a list type manipulation), contributes to the EEM effect. Distinctiveness processing may be thought of as the perception and assessment of consecutive emotional and neutral trials, when emotional stimuli are said to possess a primary distinctiveness (Schmidt, 1991); thereby enhancing the mnemonic value of emotional stimuli compared to neutral stimuli. Consequently, the extant research ascribes the significant list type x EEM interaction to distinctiveness processing (when semantic relatedness and attention are equated). However, research has merely *described* a change in relative memory performance of emotional and neutral stimuli between pure and mixed lists, and it has yet to sufficiently *explain* why this is the case. For instance, during mixed lists other cognitive factors may be characteristic

of the processing which contributes to the EEM effect. The better characterisation of distinctiveness processing is therefore a central aim of the current investigation.

We speculate here and in previous work (Barnacle, Tsivilis, Schaefer & Talmi, *in prep.*) that distinctiveness processing may be better thought of as a processing 'state'; evident throughout mixed lists, serving as a cognitive task-maintenance strategy in light of the changing properties of the stimuli (in line with one definition of distinctiveness processing; Hunt & McDaniel, 1993). Specifically we speculate that a distinctiveness processing state would represent one kind of list-long processing over and above individual stimulus processing (Dosenbach et al., 2006; Düzel et al., 1999). For instance, during mixed list encoding one might require attention and attentional control (to changing task demands of processing different stimuli presented consecutively), and working memory (to hold previous stimuli in mind enabling the perception and processing of differing stimulus properties). Indeed we already have evidence of a list type dependent encoding mechanism using electroencephalography (EEG; Barnacle, Tsivilis, Schaefer & Talmi, *in prep.*); and we now seek to extend this work by exploring the neural loci of these factors using fMRI. Such evidence would shed light on the characteristics of distinctiveness processing as it influences the EEM.

5.1.2. Experiment aims and hypotheses

The aim of the current study was to examine the neural data for evidence to answer several questions: a) where there existed at encoding a neural basis of a so-called distinctiveness processing state in mixed lists (main effect of list type); b) whether neural data could shed light on the potential mechanism of distinctiveness processing

(i.e. do results of main effect list type point to areas known for specific cognitive processes); and c) how this state might contribute differentially to emotional versus neutral memory.

We also sought to examine the behavioural data for evidence of cognitive contributions to the EEM evident at *retrieval* (as per Talmi, 2013, consistent with von Restorff, 1933). For example, the order of free recall output has been used as an indicator of the contribution of semantic relatedness to memory (Howard & Kahana, 2002; Polyn et al., 2009a). If semantic relatedness information is utilised during recall, this could act as a cue from which the memory of any stimulus with item information can be recalled; and if successful, can result in the clustering of consecutive same-category items, which may be beneficial to memory (Shiffrin, 2003).

We hypothesised that when stimuli are controlled for semantic relatedness behavioural data would replicate previous work, demonstrating no pure list EEM but a significant mixed list EEM (Talmi & McGarry, 2012; Talmi, Schimmack, et al., 2007). We also hypothesised that clustering at recall would aid memory, although we had no a-priori expectations of whether this would affect memory of emotional or neutral stimuli differently.

For the fMRI data, we predicted that successful encoding of emotional compared to neutral stimuli would elicit activity in different areas of the brain; demonstrating the potential utility of an overarching distinctiveness processing state in mixed lists which could promote continued processing in light of these ever changing encoding demands. As evidence of the influence of list type (or distinctiveness processing), we predicted that encoding of a given stimulus,

regardless of valence, would be influenced by the type of encoding list. In particular, in mixed compared to pure lists, we predicted that greater involvement of the ventral attention network would be associated with successful emotional memory, as this region is known to aid in the reorienting of attention to emotional, salient stimuli (Corbetta, Patel, & Shulman, 2008; Viviani, 2013; Vossel, Geng, & Fink, 2014). For neutral items we predicted that neural evidence would highlight where a deficit of processing occurred in mixed compared to pure lists; and we hypothesised that this may be evident in medial temporal lobe (MTL) memory regions, inferior frontal cortex, fusiform cortex, premotor cortex, and/or posterior parietal cortex (based on the meta-analysis of Kim, 2011). We also hypothesised that results of the 3-way interaction analysis (list type x valence x memory) would reveal brain regions with a greater difference in activation for recalled versus forgotten emotional items compared to those of neutral items, in mixed compared to pure lists. We speculated that this would be evident in areas of the ventral attention network (Corbetta et al., 2008; Corbetta & Shulman, 2002).

In order to test this we employed the subsequent memory paradigm which involves the measurement of brain activity at encoding and the categorisation of experimental events according to their later memory status as remembered or forgotten (Brewer, Zhao, Desmond, Glover, & Gabrieli, 1998; Paller, Kutas, & Mayes, 1987). Importantly, the encoding activity predictive of successful subsequent memory (over and above encoding processes per se) can be delineated by subtracting brain activity elicited by forgotten items from the brain activity elicited by remembered items (Brewer et al., 1998; Paller & Wagner, 2002) – the so called Dm effect (difference due to memory); see Chapter 2 – General Methodology for more details.

5.2. Methods

5.2.1. Participants

Twenty three female participants were recruited via online advertising on a job exchange website of the University of Hamburg (“Stellenwerk”). Of these one participant was removed from analysis due to non-compliance with instructions, leaving a total of twenty two participants (mean age 26 years). Female only subjects were chosen due to the gender-dependent lateralisation of amygdala activity suggested to occur in such emotional memory paradigms (Cahill, Uncapher, Kilpatrick, Alkire, & Turner, 2004; Cahill et al., 2001). Participants provided informed consent, and consulted with a medical physician before scanning commenced to ensure suitability for the experiment. Ethical approval was obtained from the local ethics committee (‘Ethik-Kommission der Ärztekammer Hamburg’).

5.2.2. Materials

The current study used colour pictorial stimuli taken from the wider sample of Barnacle, Madan and Talmi (*in prep*), to which the author refers interested parties. In brief: stimuli consisted of two sets – neutral (non-emotional) and emotional (negative) which were matched for within-set semantic relatedness; see Table 5.1 for details⁴. Each set contained 96 experimental images and 16 buffers. Images were assigned to one of four experimental conditions: pure neutral, pure negative, mixed neutral, and mixed negative. Images were presented in 16 lists (8 x mixed lists, 4 x pure neutral, 4 x pure negative) containing 14 pictures each, where the first two

⁴ Emotional and neutral stimuli were rated for arousal and valence using the SAM scales (Bradley & Lang, 1994); and for semantic relatedness as measured by how similar a trial stimulus was to a set of category exemplars.

images were buffer images to reduce primacy effects (removed from analysis). Mixed lists contained two buffers (one of each valence) followed by six images from both the negative and neutral sets, randomised in order. Pure lists contained two same-valence buffers followed by twelve same-valence images (either all neutral or all emotional). Picture allocation to list type, order of lists, and picture order within lists were pre-randomised for each participant and stimulus check-lists created of each list for real-time coding of free recall responses (recalled items ticked). The total number of pictures in each category reflected the removal of three pictures from the behavioural and fMRI analysis (2 unintentional duplicates, and one poor quality picture). In addition to real-time coding, a digital audio recording device (SONY IC Recorder) placed next to the fMRI experimenter-participant intercom was used to record all free recall responses for later free recall coding verification when required.

Stimulus presentation for this experiment was realised using Cogent 2000 (Wellcome Department of Imaging Neuroscience, UCL, UK; http://www.vislab.ucl.ac.uk/cogent_2000.php).

Table 5.1. Mean scores of arousal, valence, and semantic relatedness for each set of pictures

	Neutral	Emotional
Arousal*	2.34 (1.36)	5.65 (1.47)
Valence*	5.34 (0.49)	2.81 (0.66)
Semantic Relatedness	5.22 (1.31)	4.81 (1.24)

*Each participant contributed a mean rating score for each measure, calculated as the average score across all stimuli of each category (emotional / neutral). Data here is the grand average across all participants. Standard deviation presented in parentheses. *indicates significant difference at $p < .001$. Both arousal and valence measures were rated on a scale of 1-9 (as per SAM scale, Bradley & Lang, 1994); semantic relatedness was rated on a scale of 1-7, 1 = low, 7 = high relatedness.*

5.2.3. Procedure

After providing informed consent, participants underwent a practice session containing all tasks that they would complete during scanning with full, detailed instructions, and an opportunity to ask any questions. Participants underwent 16 experimental blocks which each contained four tasks: baseline task, list encoding, distractor task, and free recall (see Figure 5.1).

5.2.3.1. Baseline task

During the baseline task, participants were instructed to respond by button press to an arrow presented on the screen (response indicated the direction of the arrow). Arrows were presented one at a time for a fixed duration of 1500ms and pointed either to the left or right of the participants' field of view. Each block contained 14 arrow trials, amassing to 21 seconds. This baseline task was chosen in order to provide a hippocampus independent task with which we could contrast encoding data instead of using imaging data from the distractor task or fixation. This is because previous studies have found a relatively high level of MTL activation during simple distractor/baseline tasks, which when contrasted with tasks of interest, may leave very little MTL memory effects to be seen (Mayes & Montaldi, 2010; Stark & Squire, 2001). (See description of distractor in 2.3.3 below). Further to this, the baseline task was implemented at the beginning of each block in order to promote the returning of hippocampal activity to baseline before participants encoded a new list of pictures.

5.2.3.2. List encoding

In each block participants passively viewed 14 pictures (as described above) under intentional encoding instructions. The buffer stimuli were not included in behavioural analysis and as such act to reduce primacy effects. No orienting task was used because previous behavioural research shows an emotion x list type effect without this in a comparable paradigm (Talmi & McGarry, 2012). Each picture was presented for 2000ms (conforming to Talmi & McGarry, 2012) with a jittered inter stimulus interval of 4000ms +/- 500ms. This relatively long interval was chosen with the aim to reduce the effect of potential retrograde amnesia caused by intermixing of neutral and negative stimuli (Strange, Hurlemann, & Dolan, 2003). A fixation cross was presented 500ms before each image was displayed to indicate the imminent display of a picture.

5.2.3.3. Distractor task

After viewing the images participants engaged in an arithmetic task, which aimed to reduce recency effects (complementing the use of buffer images to reduce primacy effects). Two simple sums were presented one each on the right and left hand side of the display. Participants were asked to compute the sums mentally and identify the highest value sum relating to the right or the left of the display using the button box. The distractor task lasted for sixty seconds, after which the words 'free recall' were presented on screen. Data from this task was not analysed, although the experimenter monitored that the participant continued to compute sums for the whole time period.

5.2.3.4. Free recall

When the words 'Free Recall' appeared on the screen participants were instructed to begin freely recalling the stimuli of the current list. At this time the digital audio recording device began recording, and the check-list was consulted for real time coding of free recall descriptions (stimuli coded as recalled or forgotten). The duration of this task was 3 minutes, and all participants endured the total time regardless of whether they had finished recalling. This served to encourage further recall, especially in those participants with low motivation to continue recalling. It is notable that this time period was sufficient for the task – no participants were still actively recalling at the end of the task, and on more than one occasion participants had recalled all items of a list successfully within this time.

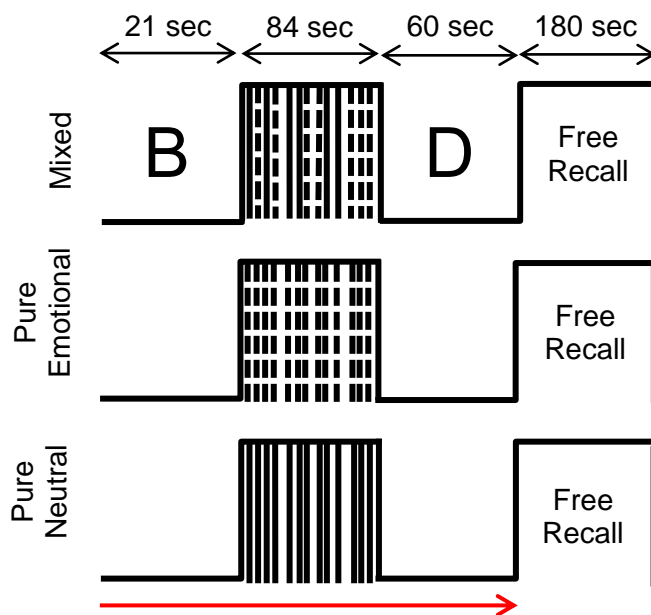


Figure 5.1. Diagrammatic representation of the three different kinds of encoding list as scanned

Each row represents the events in one condition of the experiment. B – baseline task; D – distractor task; red arrow indicates the duration of fMRI scanning. Encoding events of emotional (dashed lines) and neutral (solid lines) stimuli occur in the second task of the experiment.

5.3. Analysis

5.3.1. Behavioural analysis

In order to examine the behavioural data for list-dependent EEM effects, we computed proportion recalled scores for each condition. These were calculated as the number of recalled items of a given condition (e.g. mixed emotional recalled) divided by the total number of stimuli of that kind presented (e.g. total number mixed emotional presented). We also computed a clustering score for each participant using the LBC_{sem} – list-based semantic clustering index (Stricker, Brown, Wixted, Baldo & Delis, 2002). Using this method, any two consecutive same-category items (emotional or neutral) produced during the free recall of mixed lists were counted as a cluster. This measure provided a neat alternative to analysing neuroimaging data of EEM effects during free recall which is not practical when using fMRI (due to scanner noise, speech related artefacts etc., although see Shapira-Lichter et al., 2012 for an example of free recall scanning). In order to test whether semantic clustering at retrieval contributed to the EEM effect, we also calculated the behavioural EEM (calculated as the difference between the proportion emotional recalled and the proportion neutral recalled) for each participant, and tested the correlation of this measure with the clustering scores.

5.3.2. Functional MRI analysis

5.3.2.1. Image acquisition and pre-processing

Functional MRI data was obtained using a Siemens Trio 3-tesla scanner, with an echo planar imaging (EPI) T2*-sensitive sequence, acquiring 38 contiguous axial slices in

descending order (slices parallel to the AC-PC; 3mm thickness; TR, 2210ms; TE 30ms; flip angle, 80°; FOV, 216 x 216mm²; matrix 64 x 64, in-plane resolution 3.3mm). These scanning parameters were chosen based on a small pilot study ($n=4$), which identified the optimal scanning protocol for imaging of the medial temporal lobe (MTL).

Functional MRI data were preprocessed and analyzed using Statistical Parametric Mapping (SPM12; Wellcome Department of Imaging Neuroscience, London, UK) running under Matlab R2012a (Mathworks, Inc., Natick, MA, USA). The first 6 images of a volume were discarded because of spin saturation and because participants were adjusting to the scanner noise. Functional data were corrected for differences in acquisition time ('slice timing'), rigid body motion and susceptibility artefacts ('realign and unwarp'). Then, the individual structural T1 image was coregistered to the mean functional image generated during realignment. Coregistered T1 images were then segmented using the 'New Segment' routine. During this preprocessing step, tissue-class images for gray and white matter were generated and used within the DARTEL toolbox to create structural templates as well as individual flow fields which in turn were used for normalization to MNI space. Images were resliced with an isotropic voxel size of 2 mm. Finally, images were smoothed with a full-width half maximum Gaussian isotropic kernel of 8 mm.

5.3.2.2. fMRI statistical analysis

Encoding events were coded as recalled or forgotten post-hoc based on the participant's free recall descriptions, and categorised by encoding list (pure or mixed) and valence (emotional or neutral) – resulting in 8 experimental regressors to model.

We also modelled a number of regressors of no interest: 4 buffer regressors that did not account for memory status (mixed emotional / neutral; pure emotional / neutral); plus the arrow and distractor tasks. (Note – imaging data was not acquired during free recall.) At the first level design specification, all scans were entered together, and events were then concatenated over the sixteen sessions of the experiment (16 session constants were also modelled). Concatenating in this manner ensured that a greater number of events contributed to the estimation of the beta value for a given condition, improving reliability. Due to this concatenation procedure, it was necessary to make several adjustments to parameters which are not session specific. We first adjusted the high-pass filter to account for the possible frequencies of activation within the sixteen sessions (rather than one session, as the scans were inputted). Finally, we adjusted the autocorrelation so that only volumes acquired in succession were modelled as auto-correlated (rather than assuming consecutively entered scans were consecutively acquired and thus auto-correlated). Contrast images were created for each of the 8 regressors of interest at the first (individual) level, and entered at the second (group) level for statistical analysis.

A 4-factor flexible factorial design was specified at the second level, which modelled the main effect of subject, list type, valence, and memory. In order to control for multiple comparisons we used a combined voxel-wise significance threshold of $p < .005$ together with an extent threshold of $k_E = 20$ (based on recommendation from (Lieberman & Cunningham, 2009)). Applying this combination thresholding procedure was considered optimal for the balancing of potential type I and type II errors.

5.4. Results

5.4.1. Behavioural data

5.4.1.1. Proportion recalled

The proportion of recalled items per condition were inputted as the dependent variable into a 2 x 2 repeated measures ANOVA with list type and valence as factors. We found a significant main effect of valence, $F(1,21) = 13.340$, $p = .001$, $\eta p^2 = 0.38$; but no significant main effect of list type was found $F(1,21) = 2.51$, $p = .13$. In addition, a significant list type x valence interaction was found $F(1,21) = 11.016$, $p = .003$, $\eta p^2 = 0.33$. Further Bonferroni-corrected post-hoc paired t-tests were used to understand this interaction, and found no significant difference between memory for negative and neutral items in pure lists, $t(21) = .44$, $p = .69$. There was however, a significant difference between memory of neutral and negative items in mixed lists, $t(21) = 4.243$, $p < .001$, $d_z = 0.90$. There was also a significant difference between memory for neutral items in mixed compared to pure lists, $t(21) = -3.651$, $p = .001$, $d_z = -.78$. There was no significant difference regarding memory of negative items in mixed compared to pure lists, $t(21) = 1.803$, $p = .09$, $d_z = 0.38$. See Figure 5.2.

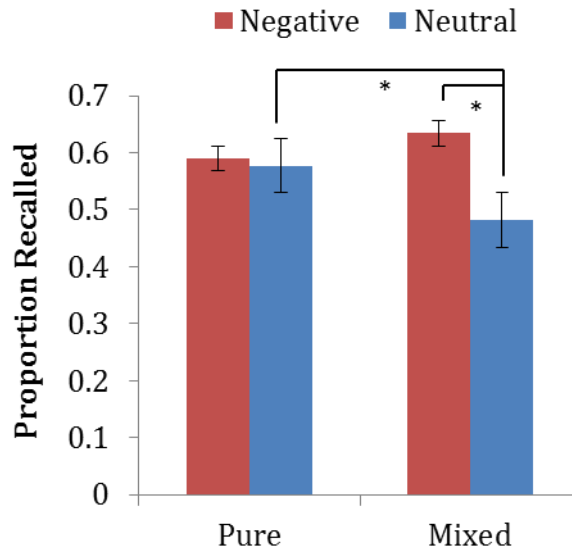


Figure 5.2. Proportion of recalled items per condition
*EEM was observed in the mixed condition but not the pure condition. Error bars represent standard error. * $p < .001$*

5.4.1.2. Free recall clustering scores

Each participant encoded and recalled eight mixed lists. For each participant an average clustering score was calculated across these eight lists using the LBC_{sem} – list-based semantic clustering index (Stricker, Brown, Wixted, Baldo & Delis, 2002). For our experiment the LBC_{sem} scores could range from $LBC_{sem} = -6$ (all items of the list recalled but no clusters present) to the maximum score of $LBC_{sem} = 6$ (all items of the list remembered, with all emotional items recalled consecutively, and all neutral items recalled consecutively). There was a moderate clustering effect evident in the data (mean $LBC_{sem} = 0.73$, sd $LBC_{sem} = 0.83$), and clustering correlated significantly with overall mixed-list memory performance $r(22) = .61$, $p < .01$. When mixed-list memory was further broken down into mixed emotional and mixed neutral memory and correlated with LBC_{sem} scores, both types of memory showed significant positive

correlations (emotional: $r(22) = .68, p < .01$; neutral: $r(22) = .47, p < .05$). However, when correlated with the behavioural EEM (calculated as the difference between the proportion emotional recalled and proportion neutral recalled), these measures were not significantly correlated (see Figure 5.3).

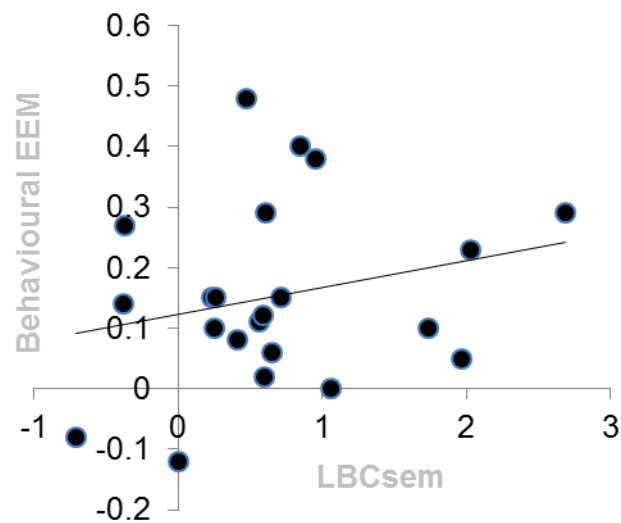


Figure 5.3. Correlation between LBCsem scores and behavioural EEM.

Correlation was not significant, $r(22) = 0.24, p = 0.28$.

5.4.2. fMRI results

5.4.2.1. Main effects

We firstly investigated the main effect of memory [recalled > forgotten]. We found many significant clusters; notably in typical medial temporal lobe (MTL) memory regions e.g. parahippocampus (peak xyz = 36, -30, -20; $Z = 4.88, k_E = 336$); hippocampus (peak xyz = -18, -22, -8; $Z = 4.11, k_E = 132$); left amygdala (peak xyz = -

18, -8, -14; $Z = 3.39$, $k_E = 60$); plus a large cluster in dorsolateral prefrontal cortex (dlPFC) extending medially to the insula (peak $xyz = -50, 26, 16$; $Z = 6.46$, $k_E = 3801$), and a large significant cluster spanning the bilateral fusiform gyrus and occipital-visual areas (peak $xyz = -46, -66, -12$; $Z = 6.34$, $k_E = 21142$); see Figure 5.4.

We also investigated the main effect of memory for emotional and neutral items separately collapsed across list-type. In order to find where the brain was uniquely activated for each valence we masked each contrast exclusively with the opposite-valence contrast (EMOTION: recalled>forgotten masked by NEUTRAL: recalled>forgotten uncorrected $p=.05$ mask, and vice versa). For the emotion contrast we found notable activations in the right anterior hippocampus (aHPC; peak $xyz = 28, -2, -22$; $Z = 3.44$, $k_E = 312$), left amygdala (AMY; peak $xyz = -18, -8, -16$; $Z = 3.41$, $k_E = 245$), thalamus (peak $xyz = -2, -16, 8$; $Z = 3.55$, $k_E = 148$), precuneus (peak $xyz = -2, -48, 16$; $Z = 2.99$, $k_E = 26$), and left dlPFC (peak $xyz = -56, 12, 14$; $Z = 4.73$, $k_E = 342$). For the neutral contrast we found memory-related activity in the bilateral parahippocampal tail (LEFT: peak $xyz = -28, -48, -10$; $Z = 4.80$, $k_E = 571$; RIGHT: peak $xyz = 30, -48, -10$; $Z = 4.49$, $k_E = 171$), posterior parietal lobe (PPL) extending ventrally and laterally into occipital visual areas (peak $xyz = 36, -64, 40$; $Z = 4.87$, $k_E = 1125$), and ventrolateral prefrontal cortex (vlPFC, peak $xyz = -44, -64, -4$; $Z = 4.68$, $k_E = 331$).

The main effect of emotion [emotional > neutral] revealed significant clusters in known emotion processing areas: notably, the amygdala (AMY, peak $xyz = 26, -4, -12$; $Z = 3.03$, $k_E = 14$), bilateral fusiform gyrus (LEFT: peak $xyz = -36, -78, -10$; $Z = 5.89$, $k_E = 785$; RIGHT: peak $xyz = 40, -64, -10$; $Z = 5.86$, $k_E = 1416$) and bilateral anterior insula (LEFT: peak $xyz = -28, 18, -16$; $Z = 3.55$, $k_E = 68$; RIGHT: peak $xyz = 30, 18, -18$; $Z = 3.12$, $k_E = 81$); see Figure 5.4.

For the main effect of list-type we were particularly interested in activations associated with greater mixed- compared to pure- list processing. For this contrast we found significant activations in executive control regions: medial prefrontal cortex (mPFC, peak $xyz = -12, 44, -14$; $Z = 4.12$, $k_E = 152$), and right inferior frontal gyrus (peak $xyz = 28, 10, -12$; $Z = 3.11$, $k_E = 23$); and in left ATL regions: left temporal pole (peak $xyz = -38, 16, -28$; $Z = 3.33$, $k_E = 53$), and left anterior superior temporal gyrus (aSTG; peak $xyz = -46, 6, -16$; $Z = 2.88$, $k_E = 20$); see Figure 5.4. To determine where the main effect of list-type varied as a function of valence and memory we conducted further interaction analyses.

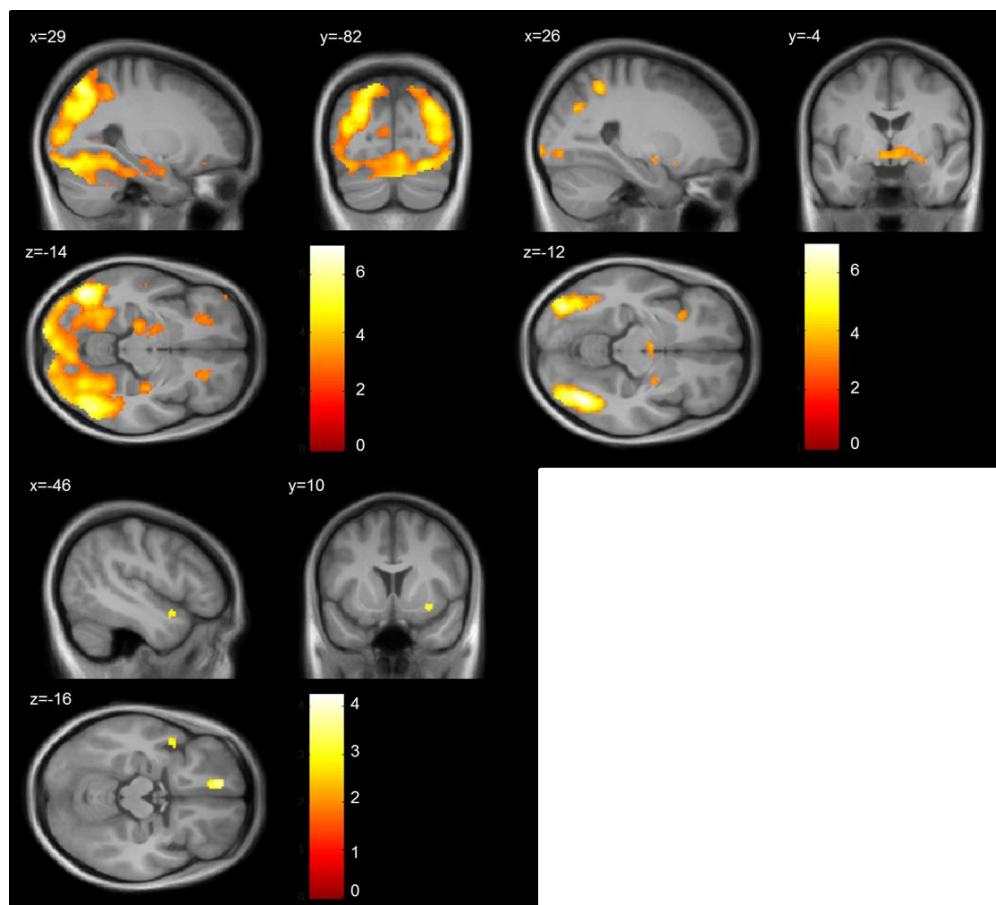


Figure 5.4. fMRI Main Effects

Main effect of memory (top left), emotion (top right), and list-type (bottom left) $p < .005$, uncorr., $k_E = 20$. Note – not all significant activations are captured in these views.

5.4.2.2. Interaction effects

To investigate how brain activation differed when processing stimuli in mixed- compared to pure- lists, we conducted a memory x list-type interaction contrast for emotional and neutral stimuli separately. Consistent with the behavioural results (although not statistically significant), we sought to probe where in the brain *emotional* items elicited greater activity under mixed list conditions compared to pure list conditions. We found a large cluster spanning ventral attention network regions in the right temporal parietal junction area (spanning angular gyrus – AnG; supramarginal gyrus – SMG; and extending anteriorly to the frontal eye field – FEF; peak $xyz = 62, -32, 32$; $Z = 3.97$, $k_E = 268$). SMG activation was also mirrored in the left homologue, although the significant cluster was smaller in size and activation not as strong (peak $xyz = -48, -22, 30$; $Z = 2.99$, $k_E = 23$). We also found activations in executive control areas: the dorsal anterior cingulate cortex (dACC; peak $xyz = -2, 18, 24$; $Z = 3.25$, $k_E = 65$); dorsomedial PFC (dmPFC; peak $xyz = -18, -22, 22$; $Z = 3.15$, $k_E = 45$); and in a left aSTG cluster (peak $xyz = -38, 4, -20$; $Z = 3.35$, $k_E = 130$).

Consistent with the behavioural results for neutral items, we sought to probe where in the brain neutral items elicited greater activity in pure lists compared to mixed lists. This interaction contrast revealed one significant activation in the right parahippocampus only (peak $xyz = 20, -26, -24$; $Z = 2.99$, $k_E = 20$).

In order to test the most crucial contrast of interest we generated a 3-way interaction t-test (list type x valence x memory). This tested the hypothesis that there would be greater difference in activation for recalled versus forgotten emotional items compared to those of neutral items, in mixed compared to pure lists. The result of this interaction revealed two significant clusters: at right SMG (peak $xyz = 54, -24, 34$; $Z = 3.25$; $k_E = 137$) and left aSTG (peak $xyz = -40, 6, -22$; $Z = 3.24$; $k_E = 61$). To

further understand this interaction, we used this result as a mask (inclusive, uncorrected mask $p=.05$) applied to the Dm contrasts (recalled minus forgotten) for each condition. The contrasts investigating the mixed neutral Dm, pure negative Dm, and pure neutral Dm did not survive masking by the three way interaction; however both clusters identified in the 3-way interaction were significant in the mixed emotional Dm contrast. We also masked the main effect of list type [mixed > pure] by this three way interaction in order to identify where a distinctiveness processing state contributed to this three way interaction. Using this method, activation in the laSTG remained significant. (See overlap of the three way interaction results with the two way interaction results in figure 5.5.)

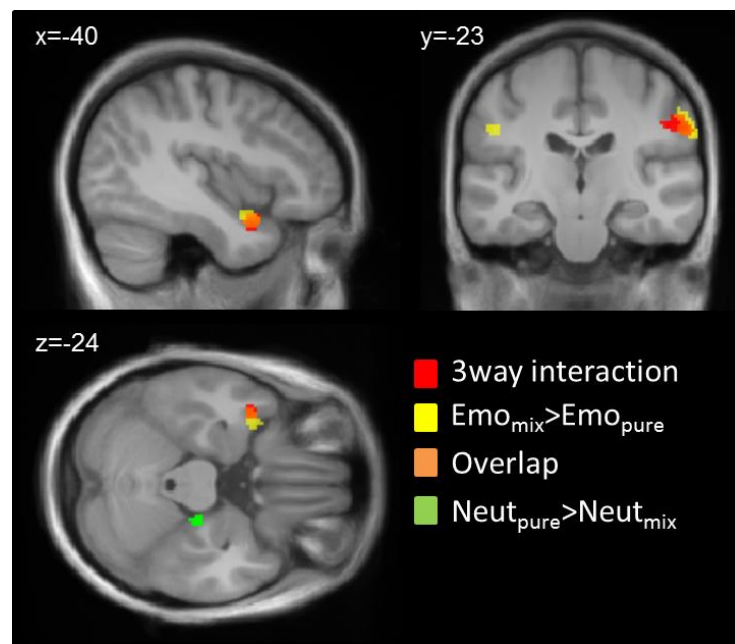


Figure 5.5. fMRI overlap between interaction effects

Considerable fMRI activity overlap (orange) can be seen between the three-way interaction (red) and the two-way emotion interaction (yellow); but not for the neutral interaction. The emotion and neutral interaction effects (yellow & green respectively) represent where Dm activity differed between list-type. Note – the view presented here does not show all significant clusters from all analyses.

Given these results, we were also interested whether the areas of significant activation were correlated with behaviour, and so pursued a further unplanned exploratory analysis. We created two regions of interest (ROI), which were masks of each of the significant clusters from the 3 way interaction above (rSMG, laSTG). Then, using the Marsbar toolbox in SPM, we extracted the mean activation from the area within each mask from first level contrast images of the mixed emotional recalled and mixed emotional forgotten contrasts for each of the participants. Using this extracted data we computed a proxy for the neural mixed emotion Dm (mixed emotional recalled minus mixed emotional forgotten). We hypothesised that, across participants, this neural mixed emotional Dm measure in each of the ROIs would be significantly correlated with behaviour as measured by the average proportion of mixed emotional recalled pictures. We found a significant correlation between these two measures for the rSMG ROI: $r(22) = .43, p < .05$ (see figure 5.6); but not for the laSTG ROI: $r(22) = .02, p = .92$.

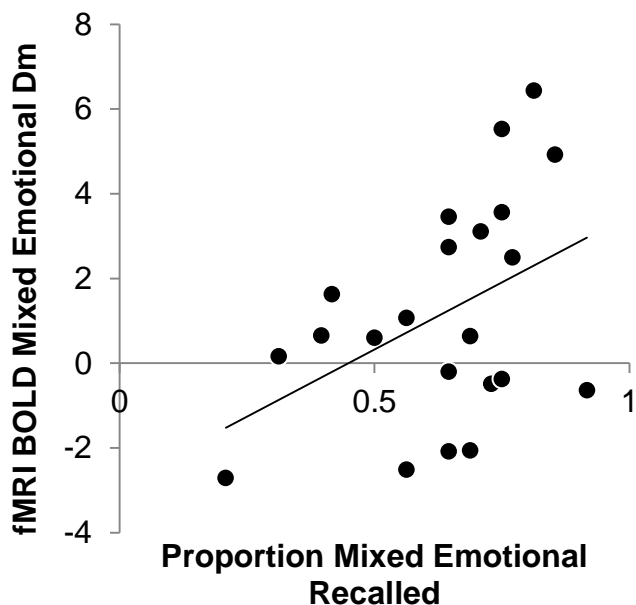


Figure 5.6. Correlation between behavioural and fMRI BOLD data

Significant correlation between the behavioural measure 'proportion recalled mixed emotional stimuli' and fMRI BOLD response in the rSMG relating to the neural mixed emotional Dm. Black line shows linear trend.

However, caution should be exercised in interpreting these correlation results, as this was a post-hoc analysis which only came to be of interest *after* looking at the interaction results.

5.5. Discussion

5.5.1. Behavioural data

As expected, the behavioural results in this study showed no significant EEM effect in pure list comparisons of subsequent emotional and neutral memory, but a significant EEM effect evident in mixed lists. Replicating previous work, our results suggest that this mixed list EEM effect is driven by a reduction in memory for neutral items rather than an increase in memory for emotional items (Barnacle, Tsivilis, Schaefer & Talmi, *in prep.*; Talmi, Luk, McGarry, & Moscovitch, 2007). This implies that mixed-list conditions invoke processing (distinctiveness processing) that is beneficial for emotional items and detrimental to neutral items. We also investigated the behavioural data for evidence of memory-associated effects at retrieval. Using the LBC_{sem} (Stricker, Brown, Wixted, Baldo & Delis, 2002), cluster analysis showed a significant correlation between the proportion of items recalled (in mixed lists) and a participant's LBC_{sem} score. This is so far unsurprising given that we know memory is improved when a participant make use of category / semantic information during free recall (Bousfield, 1953; Cofer, Bruce, & Reicher, 1966; Howard & Kahana, 2002; Polyn et al., 2009a, 2009b). However, given that clustering scores did not significantly correlate with the behavioural EEM, it appears that clustering is a retrieval strategy that aids memory per se, but that does not significantly contribute to the EEM effect under the conditions of this experiment. Although we recognise that there may be many other cognitive contributions to retrieval effects associated with a subsequent

EEM, the limited data that we tested in the current study only supports the argument for encoding – not retrieval – effects.

5.5.2. Functional MRI data

5.5.2.1. Main effects interpretation

For the main effect of memory, we found typical activations in the left lateralised PFC, hippocampus and parahippocampus, fusiform gyrus, and posterior parietal lobe regions (consistent with Dickerson et al., 2007; Rugg, Otten, & Henson, 2002; Uncapher & Wagner, 2009; Wagner, Koutstaal, & Schacter, 1999). We also found significant activations in occipito-visual areas such as the primary visual areas and lateral occipital cortex (LOC) – activations more often associated with visual perception and less-commonly associated with memory processes. We believe this to be primarily due to the fact that retrieval using free recall necessarily relies on accurate and detailed visual encoding to afford enough information / cues for participants to recall spontaneously at the time of retrieval (Shiffrin, 2003). Notably there is a dearth of data to support this assumption; possibly because neuroimaging of memory is more often traditionally probed with recognition paradigms (Brewer et al., 1998; Rimmele, Davachi, Petrov, Dougal, & Phelps, 2011; Wagner, 1998; Yonelinas, Aly, Wang, & Koen, 2010 but see Dolcos & Cabeza, 2002; Shapira-Lichter et al., 2012) and word memory paradigms (Brassen, Weber-Fahr, Sommer, Lehmbeck, & Braus, 2006; Fitzgerald et al., 2011; Mneimne et al., 2010; Staresina & Davachi, 2006); and because the main contrast of interest that is reported is often an interaction with memory (e.g. Parent et al., 2011). However, one study that investigated memory for

pictorial stimuli whilst scanning using fMRI did *not* find evidence of visual-occipital activation predictive of free recall (Dickerson et al., 2007). We interpret this disparity in terms of the stimuli used: although both were pictorial stimuli, those of Dickerson et al. were very basic (common objects) where stimulus labels e.g. “hammer” may have been the focus of encoding; compared to our stimuli which were complex scenes that could not have been easily labelled, and therefore may have required greater visual encoding to aid later memory. In addition to enough visual information to allow spontaneous recall, for the experimenter to properly categorise an event as recalled or forgotten this requires an accurate and adequate description of the stimulus, which is – in part – made possible by rich visual encoding. In line with this proposed explanation, enhanced visual area activation has been associated with levels of subjective perceptual vividness leading to subjective mnemonic vividness (Todd, Schmitz, Susskind, & Anderson, 2013).

Our investigation of the main effect of list-type was of importance to our argument regarding a list-dependent encoding mechanism, as it highlighted the core network which facilitated processing under mixed list conditions. We envisage this as the foundation with which the brain manages successive encoding under changing circumstances regardless of the category membership of each stimulus (emotional / neutral). Our findings are consistent with our hypothesis regarding a distinctiveness processing state that we presume governs the transition between the different encoding mechanisms for emotional and neutral stimuli (discussed below). This is evident in the right inferior frontal activation, a region associated with mediating between the dorsal (top-down) and ventral (bottom-up) attention networks (Fox et al., 2006; Vossel et al., 2014). In addition to this, we identified a significant activation in the left medial PFC. This region is said to be functionally connected to MTL regions

during encoding tasks; with differential connectivity between these regions for schema-consistent and schema-inconsistent stimuli (Garrido, Barnes, Kumaran, Maguire, & Dolan, 2015; van Kesteren, Ruitter, Fernández, & Henson, 2012). For example, schema-inconsistent stimuli are associated with greater functional coupling of the mPFC with MTL memory regions (van Kesteren, Fernández, Norris, & Hermans, 2010). In consideration of the current design, it is plausible that in pure lists a schema is quickly formed as all items of the list are consistent to the theme (or schema); whereas in mixed lists it is plausible that an attempt is being made at the formation of two independent schemas consistent with the two kinds of valenced stimuli (as two distinct categories), which would implicate more sustained activity of the mPFC region. According to van Kesteren et al, the mPFC would be activated by the transition between one schema and another – i.e. when the current trial is of a different category to that of the previous trial. As this situation only occurs in mixed list conditions, it is sensible that this region be identified in the mixed > pure main effect contrast.

5.5.2.2. Precursor to a distinctiveness processing state

Our argument for a distinctiveness processing state is predicated on our interpretation of Hunt and McDaniel's (1993) definition, and assumes differences in successful encoding activity associated with each category of stimulus. Two separate fMRI contrasts (one for each valence) confirmed evidence of unique encoding effects, and found a dissociation of successful encoding activity along the longitudinal axis of the MTL in hippocampal and parahippocampal regions (aHPC – emotional items; pPHC – neutral items; consistent with Dolcos et al., 2004). For the neutral items

successful subsequent memory was associated with a distinct bilateral pPHC activity pattern which was not evident in the memory contrast for emotional items. It is noted that this appears a somewhat unusual result, because one would assume that successful encoding would also recruit HPC processing regardless of stimulus-valence. However, it should be understood that this contrast identified activity that was exclusively correlated with neutral memory, and does not rule out HPC activation common to neutral and emotional memory. We interpret this parahippocampal activity as reflecting a relative greater contribution of contextual processing for neutral items (Aminoff, Kveraga, & Bar, 2013). Given that stimuli were controlled for within-set semantic relatedness (providing an equal measure of context for both kinds of stimuli), this reliance on parahippocampal activity for successful neutral encoding implies that contextual processing for neutral stimuli is effortful / intentional, and serves as a crucial part of the mnemonic strategy.

Conversely, distinct anterior hippocampal and amygdalae activations were associated with successful subsequent memory of emotional items – activation that was not present in the neutral memory contrast. This is consistent with the understanding that memory is modulated by activity of the amygdala in emotional conditions (LaBar & Cabeza, 2006; Lisman & Grace, 2005; McGaugh, 2004, 2013; Poppenk, Evensmoen, Moscovitch, & Nadel, 2013); although most of the studies evidencing the modulation of emotional memory by the amygdala test memory after a delay (Canli, Zhao, Brewer, Gabrieli, & Cahill, 2000; Canli, Desmond, Zhao, & Gabrieli, 2002; Dolcos et al., 2004; Kilpatrick & Cahill, 2003). Studies that tested recognition memory at a shorter encoding-test delay of 45 minutes (Kensinger & Corkin, 2004) or 20 minutes (Ritchey et al., 2008) also found amygdala activations correlated with successful subsequent memory of emotional but not neutral items. However, the lack

of immediate free recall memory testing of the EEM effect (i.e. after a delay that only interrupts working memory ~60s, such as that of the current design) means that although we can glean supporting evidence from *similar* studies, this finding may be novel. Although previous research has already demonstrated that amygdala activation at encoding has a 'long-acting' effect (i.e. involved in consolidation processes over hours, days, or weeks); the current research may be the first to evidence the short-acting contribution of amygdala activation to the immediate EEM which correlated with memory as tested 'before' consolidation using free recall.

Together these results provided evidence that to successfully encode emotional and neutral stimuli one employs different encoding strategies (Dolcos, LaBar, & Cabeza, 2004; Erk et al., 2003; Kensinger & Corkin, 2004; Ritchey et al., 2008), which is consistent with our suggestion of the possibility that an additional mechanism – the distinctiveness processing state – may be required to aid the smooth transition between differential processing of these items in mixed lists; which we investigated by conducting planned interaction analyses, as follows.

5.5.2.3. List type dependent encoding

We next sought to identify the neural correlates of mixed compared to pure list processing which specifically aided the memory of emotional or neutral items – evidence that a given item would be processed differently according to the type of list. In support of our hypothesis we found that emotional items elicited more activity in the ventral attention network (broad TPJ area activations; Corbetta & Shulman, 2002) in mixed compared to pure lists. This is a logical finding given that this network is associated with reorienting to salient (emotional) stimuli from relatively less salient

stimuli (Corbetta et al., 2008); and given that in pure lists no reorienting would be necessary due to the consistency of the valence within these lists. We also identified activity in the dACC which is proposed as a ‘comparator’ region, assessing alternative stimuli (Kolling, Behrens, Mars, & Rushworth, 2012), and as a mediator of top-down control under circumstances of high cognitive load and threat (Clarke & Johnstone, 2013). As applied to the current findings, it is speculated that when reflexive attentional reorienting is indicated by the presence of a salient (emotional) stimulus, TPJ-VAN area activation increases; however this is moderated by dACC activity, which promotes control over this process, enabling continued encoding of proceeding items. This explanation is also consistent with the findings that the dACC (along with medial superior frontal cortex) has a role in “set-maintenance”, promoting consistent processing across stimuli within a set (e.g. an encoding episode of multiple trials), unrelated to specific attributes of individual set stimuli (Dosenbach et al., 2006).

In addition to these control and attentional processes, activation in ATL regions point to semantic processing as part of the mechanism explaining better emotional memory in mixed compared to pure lists. However, the function of the anterior temporal lobes (ATLs) are debated: with some arguing for the ATL as a general semantic processing region (the Semantic Hub Account, and the “hub and spoke” model; McClelland & Rogers, 2003; Visser, Jefferies, & Lambon Ralph, 2010; Visser & Lambon Ralph, 2011); whilst others advocate for a role in *social* semantic processing specifically (the social knowledge hypothesis; Olson, McCoy, Klobusicky, & Ross, 2013; Ross & Olson, 2010; Wong & Gallate, 2012). Moreover, as we did not directly manipulate the level of semantic processing, we treat this conclusion with caution, and acknowledge a level of reverse inference. With respect to the current data greater ATL activation for recalled emotional stimuli in *mixed* lists may be due to

the changing nature of the stimuli: Each stimulus requires a separate (social) semantic assessment, as it is not apparent whether each consecutive stimulus will fit with the previous (social) semantic assessment. This is not required in pure lists because each stimulus is consistent with a generalised (social) semantic assessment that broadly applies to all stimuli in the list.

We also found evidence that neutral items were processed differently according to list composition, evident in significantly greater activation in the right PHC for pure compared to mixed lists. This is unsurprising, given that PHC activation was identified as the unique activity associated with neutral processing per se, and given the behavioural result of lower rates of mixed compared to pure neutral recall. As per our previous interpretation, we propose that this represents the effortful processing of context and contextual relationships among neutral items (Ranganath & Ritchey, 2012), and the particular processing of scene information and spatial context (Aminoff, Kveraga, & Bar, 2013; Bar & Aminoff, 2003; Epstein & Kanwisher, 1998). This forms a crucial part of the mnemonic strategy in pure lists when a continuous processing strategy is afforded, but this becomes demonstrably less available when disrupted by more salient items (i.e. in mixed lists).

Together, this evidence suggests that the composition of the list has an effect on the processing of a given item over-and-above any stimulus-specific processing, consistent with our proposal of a distinctiveness processing state.

5.5.2.4. A neural list type dependent EEM effect

The results of the three-way interaction analyses complete the picture of a mechanism of immediate EEM encoding effects, dependent on list type. These results

demonstrate that in addition to the effects already described above, the three-way interaction was driven by a significant mixed-list emotional Dm effect at rSMG and laSTG, whereas no other Dm effects were significant within the regions identified in this analysis. Furthermore we found that of these two regions, only activity in the rSMG correlated with behavioural measures (proportion mixed emotional recalled). We tentatively suggest that these activations serve a collaborative function (Binder & Desai, 2011; Viviani, 2013) as constituents of the ventral attention network (Humphreys & Lambon Ralph, 2014) and semantic networks respectively (McClelland & Rogers, 2003). Results of the correlation analyses suggest that bottom-up attention played a direct role in the memory of these items – i.e. when SMG activation was greater, mixed emotional memory was improved. However, given that this was not borne out statistically in the behavioural data, it may be better concluded that this mixed list emotional encoding mechanism is different from (not greater than) that employed in pure lists, and may provide clues as to why neutral memory is relatively poor (i.e. the grabbing of attentional resources by emotional stimuli).

Following from this reorienting process, we speculate that bottom-up attention to emotional items acts as a crucial gated mechanism for access to further stimulus elaboration provided by the aSTG in the form of social semantic processing. However, given that activation of the aSTG does not correlate significantly with behaviour, we suggest that this region may be an intermediary in successful emotional encoding. As the ATs are optimally positioned lateral to the emotion centre of the MTL (amygdala), with known connections via the uncinate fasciculus (Catenoix, Magnin, Mauguère, & Ryvlin, 2011; Kier, Staib, Davis, & Bronen, 2004; Olson et al., 2013; Ranganath & Ritchey, 2012; Skipper et al., 2011) we speculate that the final crucial step in maximising encoding of emotional items in mixed lists could

be envisaged as a reciprocal connection between the ATL and AMY: When mixed-list emotional items initiate reorienting attention processes in the ventral attention network (rSMG), the aSTG sets about processing the social semantic information of the stimulus, which at a certain threshold signals to the AMY to upregulate HPC activation, thus rendering encoding more successful. If the activation at any stage along this proposed pathway (ATL – AMY – HPC) does not reach the required threshold, this may render memory unsuccessful, even though initial ATL activity was high, thus potentially explaining why a linear relationship with emotional memory may not be evident in this area.

Overall our speculations of a mixed list immediate EEM model (see figure 5.7) lends itself well to a connectivity approach, and indeed it is a goal for future investigation to test the assumptions made here using dynamic causal modelling. Any future modelling will be strengthened by our previous results using EEG, which can help to form hypotheses about the temporal order of activations. For now, we have begun the characterisation of a neural distinctiveness processing mechanism, and made in-roads to describing such a mechanism's contribution to the immediate EEM.

5.6. Conclusions

The aim of this research was to explore the neural underpinnings of differential processing relating to emotional and neutral stimulus encoding, predictive of subsequent memory. We were particularly interested in mixed lists where a *behavioural* EEM is evident (not evident in pure lists when semantic relatedness is controlled), and sought to understand and characterise the potential neural correlates of a 'distinctiveness processing' state (assumed to be active in mixed lists) which we

hypothesised contributed to the immediate EEM. Our fMRI results have lead us to develop a speculative proposal for a multi-layered model of this effect (see Figure 5.7). We have successfully demonstrated evidence of a neural mixed-list processing state, and identified a potential network of brain regions which are specifically beneficial for the memory of emotional items in mixed- but not pure- lists, and not for neutral items. These findings add important neural data to our understanding of the EEM and its cognitive influences. It will be important for future research to investigate whether these correlates of distinctiveness processing have a lasting impression on memory, and therefore also predict memory performance after a delay. Understanding the contribution of cognitive factors to the immediate / delayed EEM may prove a useful addition to existing models.

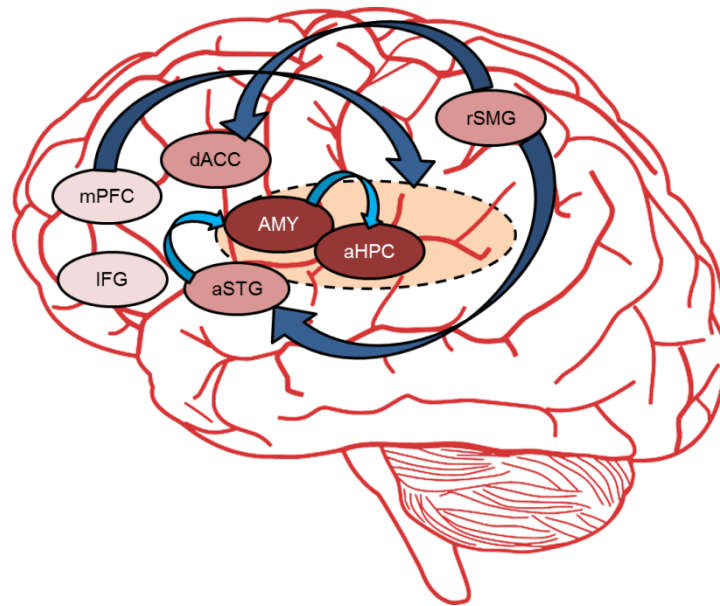


Figure 5.7. Preliminary proposal for a model of list type dependent EEM in the brain

Emotional memory is associated with AMY and aHPC activation, regardless of list-type. However, in mixed lists the mPFC has a greater functional connectivity to the MTL regions due to the changing stimulus properties, which upregulates encoding activity in these regions. IFG is also a part of the neural system that supports mixed list processing, affording sustained, controlled processing when ‘switching’ between stimuli processing in mixed lists. For emotional items specifically, during mixed lists ventral and dorsal attention networks interact to enable successful encoding – rSMG reorients attention to salient emotional stimuli, and dACC modulates this to reduce distraction due to emotion. When attention is reoriented to these emotional stimuli, this enables further social semantic processing of these items, evident in the aSTG. Finally, via the structural connection of the uncinate fasciculus, the aSTG and AMY process the emotional content of these pictures, determining the level of threat posed, and appropriate neurobiological response. This input to the AMY from the aSTG may further upregulate emotional stimulus encoding in the aHPC.

Diagram is not intended to represent the proportions or scale of the brain; direction of connectivity not limited to the direction of arrows shown here. Levels of this proposed mechanism are denoted by the colour of the brain region label from specific (emotional memory, dark red), to less specific (mixed-list emotional memory, medium red), to more general (distinctiveness processing per se, light red). Area demarcated by peach background and dotted lines represents the MTL. Dark blue arrows denote a suggested functional connectivity, whereas light blue arrows denote a suggested structural connectivity.

6. Can manipulating distinctiveness processing at encoding alter the Emotional Enhancement of Memory effect?

Abstract

Distinctiveness processing as a cognitive mechanism has been defined as the combination of relational and item-specific processing, which when employed together results in optimal memory performance. Investigations of emotional memory have cited distinctiveness processing as a contributory factor to the emotional enhancement of memory (EEM) effect, however these studies have not so far further-specified the mechanism of distinctiveness processing. In this experiment we replicated our previous paradigm of our lab which manipulated 2 repeated measures factors: valence (emotional and neutral stimuli) and list type ("pure" encoding lists of only emotional or neutral stimuli, compared to "mixed" lists of both emotional and neutral stimuli); where mixed lists were supposed to invoke distinctiveness processing. We tested immediate free recall memory using this paradigm in three independent groups of participants: a baseline group replicating previous work; an item-specific processing group ("ITEM"); and a relational processing group ("RELATE"). Our results showed no significant differences in memory for the RELATE and baseline groups; suggesting relational processing was common in both groups. Crucially, when relational processing was eliminated this was detrimental for neutral memory, and resulted in more retroactive interference (incidence of forgotten neutral stimuli which were presented before an emotional stimulus) relative to the baseline group. We therefore propose that relational processing acts as a protective mnemonic mechanism for neutral stimuli in mixed lists. Overall our results show differential importance of item-specific and relational processing to the EEM effect. Implications for the definition of distinctiveness processing and its applicability as an explanation of the EEM effect are discussed.

6.1. Introduction

The Emotional Enhancement of Memory (EEM) effect refers to the better memory of emotional compared to neutral information or events. It has been suggested that the EEM effect is largely automatic, due to bottom-up processes (e.g. in the emotional Stroop task; Williams, Mathews, & MacLeod, 1996), based on the evolutionary adaptive benefit of attending to such emotional information. Researchers have long acknowledged the notion of interacting yet distinct psychological and neural processes for bottom-up and top-down attention (Corbetta et al., 2008; Corbetta & Shulman, 2002; Vossel et al., 2014); for example suggesting that bottom-up attention could interrupt on-going task processing, and that top-down processing could filter reflexive signals from bottom-up attention (Fox et al., 2006). This may suggest that one could reduce bottom-up processing – beneficial for emotional encoding – by increasing top-down processing, alluding to these systems being mutually inhibitory (Mathews, 2004). For example, one fMRI study showed that increasing cognitive load whilst encoding emotional stimuli resulted in greater deactivation of emotion-related processing regions (Grimm, Weigand, Kazzer, Jacobs, & Bajbouj, 2012). This phenomenon has been noted to have potential applications for therapeutic interventions such as those that would seek to help with troublesome intrusive emotional memories e.g. persons diagnosed with post-traumatic stress disorder (PTSD), depression, and anxiety; or those at risk of such disorders. A recent clinical trial showed that participants diagnosed with PTSD allocated to the treatment group (Narrative Exposure Therapy, a cognitive intervention), demonstrated increased top-down processing during the viewing of aversive stimuli (threat cues), which correlated with reduced PTSD and depressive symptom scores relative to PTSD

controls (Adenauer et al., 2011). One aim of the current investigation was to explore whether increasing top-down processing by using instructions regarding encoding, could alter the EEM effect by reducing bottom-up processing for the emotional stimuli.

Despite the automaticity of emotional encoding, research also suggests that one can inhibit or regulate the emotional response under instructions to do so (Izard, 2010; Jackson, Malmstadt, Larson, & Davidson, 2000; Kohn et al., 2014). This has typically involved attenuating the *experience* of emotion (e.g. arousal), which could reduce subsequent emotional memory by altering processes of preferential emotional-stimulus consolidation (conforming to the modulation model; McGaugh, 2004). However, recent research suggests that beyond the contribution of arousal to the EEM effect, cognitive factors may also play a role (mediation theory; Talmi, 2013). Therefore using instructions to manipulate cognitive factors at encoding may present an alternative method to alter the experience and subsequent memory of emotional stimuli.

6.1.1. Distinctiveness processing and cognition

One such cognitive process of interest is ‘distinctiveness processing’ which is inherently linked to – but different from – distinctiveness per se which can be thought of as a property of the stimulus. For example, when stimuli possess a categorical membership (e.g. words belonging to different categories such as ‘animals’, and ‘food’) and are presented intermixed in one encoding list, these relative categorical differences afford the stimuli a relative distinctiveness (Schmidt, 1991; Siegel, 1943; Wallace, 1965). However, before the distinctiveness of a stimulus can be determined,

the properties of the stimuli must first be perceived, interpreted, and – crucially – compared relative to those held in working memory: this is the process of distinctiveness processing. Distinctiveness processing is often operationalised by manipulating the encoding list: comparing pure encoding lists (stimuli of all one category, resulting in no-, or less distinctiveness processing) to mixed encoding lists (stimuli of two or more categories, resulting in distinctiveness processing). For example in the EEM literature Talmi, Luk, McGarry, and Moscovitch (2007) showed that when other cognitive factors were controlled in pure lists (no distinctiveness processing condition) the EEM effect was not apparent; however in mixed lists when distinctiveness processing is thought to manifest, the EEM effect was present.

One challenge with interpreting these results is that distinctiveness processing is a psychological construct which may represent a constellation of cognitive processes; and currently lacks an adequate characterisation. The problem with characterising distinctiveness processing is not a new one: to paraphrase Schmidt (1991), “explanations appear to be circular, in that good memory performance is used as an index of distinctiveness [processing], and distinctiveness [processing] is invoked to explain good memory performance” (pp. 524). One way to attempt better characterisation of such a psychological construct is to employ neuroimaging techniques to obtain evidence of correlated brain function during distinctiveness processing. Indeed our recently gathered neuroimaging evidence using electroencephalography (EEG; Barnacle, Tsivilis, Schaefer & Talmi, *in prep.*) and functional magnetic resonance imaging (fMRI; Barnacle, Montaldi, Talmi & Sommer, *in prep.*) lead us to speculate that attentional and semantic processing may be key to the mechanism of EEM as influenced by distinctiveness processing (i.e. in mixed lists). Our interpretation of these two neural correlates of the mixed list EEM effect marry

nicely with one definition of distinctiveness processing, which describes this construct as relational processing – akin to semantic processing; and item-specific processing – a stimulus driven attentional processes (Hunt & McDaniel, 1993). Although the neural evidence may give a preliminary indication of how to characterise distinctiveness processing, these characteristics must be manipulated in order to test these hypotheses directly. Therefore the current study makes use of the neural evidence alongside the work of Hunt and McDaniel (1993) and colleagues, which we summarise briefly below.

6.1.2. Historical investigations of distinctiveness processing

In their definition of distinctiveness processing, Hunt and McDaniel (1993) dissociate two components of this construct: relational and item-specific processing; whereby situations that encourage both types of processing (maximum distinctiveness processing) lead to optimal memory performance. Hunt and McDaniel (1993) defined relational and item-specific processing according to previous definitions. Relational processing was defined as “a process of developing a ‘code’ common to a set of discrete elements. The ‘code’ facilitated memory by increasing the efficiency of storage and retrieval of elements” (Johnston, 1970). Item-specific processing was rather loosely defined as any processing which focussed on the individual stimulus, and not to commonalities between stimuli. In this sense we can think of distinctiveness processing simply as the processing of stimuli in light of their common and non-common properties, where both of these processes are said to be important for encoding and subsequent memory.

The claim that processing of both common and non-common features resulted in optimal memory performance was tested empirically by Epstein, Phillips, and Johnson (1975) using a study in which word pairs were presented at encoding and the target cued at retrieval using the non-target word. Word pairs were either semantically related e.g. *cake* | *muffin*; or not semantically related e.g. *cake* | *tiger*. At encoding participants either made similarity or difference judgements as an orienting task (supposed to embody relational processing and item-specific processing respectively). The results showed that the best memory was of semantically related words for which difference-judgements were made, and semantically unrelated words for which similarity-judgements were made. Their interpretation was that semantically related words already have an obvious similarity, and therefore benefit little from an additional similarity judgement. By extension, semantically unrelated words are assumed to confer some individual processing as standard, with a benefit to memory only evident when an additional similarity judgement was made.

However, operationalising distinctiveness processing as embodying similarity and difference per se can be problematic for several reasons: i) these judgements may utilise the same processing mechanism, ii) are necessarily mutually exclusive, and iii) are inversely correlated (in certain circumstances). For example, to conclude that the words *cake* | *muffin* are similar, or that the words *cake* | *tiger* are different, in both cases one must first retrieve semantic information about each individual stimulus and perform a process of comparison – i.e. the same mechanism is employed to perform both assessments. Additionally, similarity and difference will be mutually exclusive when the property of assessment is held constant. For example, if stimuli representing the categories ‘living’ and ‘non-living’ are presented, and it is the property of animacy upon which judgements of similarity and difference should be

made; then two stimuli cannot be both similar (both animate) and different (one animate and one non-animate) on this judgement. Therefore, amongst a mixed list of stimuli the number of stimuli judged to be similar would be necessarily inversely related to the number of stimuli judged to be different (i.e. as the proportion of affirmative similarity judgements increase, the proportion of affirmative difference judgements must necessarily decrease). This is consistent with Hunt and Einstein (1981), who based their definition of distinctiveness on (Tversky, 1977), stating that “distinctiveness is an inverse function of the number of features in a trace shared by other to-be-remembered events”. Given these challenges, it is pertinent to seek converging evidence using alternative encoding instructions / orienting tasks, which still embody the processing of common and non-common features of the stimuli but without drawing explicitly upon similarity and differences.

This was achieved by Einstein and Hunt (1980), who demonstrated that categorised word lists (words that shared a theme or were semantically related) benefitted most from item-specific processing using a pleasantness ratings task, whereas uncategorised word lists benefitted most from a semantic sorting task (supposed to embody relational processing). When stimuli were not semantically related, performing both item-specific and relational tasks of this kind for each stimulus produced better memory performance than for either orienting task alone, and better than either task performed twice; accounting for the possible confound of quantity of task-processing. However, one criticism of this approach is that participants may not engage with the task to the same degree the second time that they perform it compared to the first. An alternative way to test this would be to use two different tasks which target the same facet of distinctiveness processing.

Analogous to similarity, in Experiment 3, Hunt and Einstein (1981) investigate *typicality*, defined in accordance with Glass and Meany (1978) category typicality, and Smith, Shoben, and Rips' (1974) feature model. By this definition, a stimulus is deemed typical if its category membership is obvious, compared to an atypical stimulus for which membership is less obvious or less accessible; therefore representing a deficit of information for atypical stimuli at encoding (and retrieval). Hunt and Einstein (1981) tested these claims, hypothesising that a relational orienting task should reduce the difference between memory performance of typical and atypical instances (due to a shift towards typicality by relational processing). In addition, an item-specific orienting task was hypothesised to aid memory only for typical instances, due to the fact that atypical instances were already predisposed to poor memory due to lack of relational processing. Using a categorical sorting task (relational) or a pleasantness task (item-specific), Hunt and Einstein (1981) showed that there was no significant differences in memory performance of typical and atypical instances following the relational task, and that significantly more typical compared to atypical words were remembered following the pleasantness ratings task, confirming their hypotheses.

More recent research has developed mechanistic models relevant to distinctiveness processing using neuroimaging. For example the SLIMM model (van Kesteren et al., 2012) explains successful memory in terms of the neural correlates of both schema-congruent (similarity) and schema-incongruent (difference) status. Stimuli which are congruent with an existing schema (i.e. convey relatively greater similarity, or typicality) are remembered better due to activation of the medial prefrontal cortex (mPFC) and neocortex; whereas stimuli that are schema incongruent (i.e. conveying relatively greater stimulus dissimilarity, or atypicality)

are better remembered due to activation of the medial temporal lobes (MTL). Although the SLIMM model considers memory of potentially any category of event or information, when we specifically consider emotion as a category identifier, binding theory (MacKay et al., 2004) suggests that an experience of emotional content such as an emotional word or picture activates the amygdala, which in turn prioritises the binding of the emotional stimulus information to the context of encoding via connections with the hippocampus. This results in more efficient encoding of emotional compared to neutral stimuli, because of these improved stimulus-context associations.

This is particularly relevant to studies such as the current investigation which investigate the EEM and distinctiveness processing using free recall, as it has been posited that context is used as a starting point from which to search for individual stimuli in memory at retrieval (Shiffrin, 2003). This is supported by Hunt & McDaniel's claim that "any request for episodic information must carry with it some specification of the episode." In this sense, during recall it is most beneficial to first instantiate a context cue (relating to similarity or categorical information) in order to specify the episode from which to retrieve, and subsequently to instantiate some item-specific information to distinguish individual events. The context cue initiates the process of searching and sampling from memory for matching information. If any information matches the context cue, it is generated as output in recall and this item-specific information then becomes the cue for the subsequent search and sample to retrieve the next stimulus from memory, and so on. When the current stimulus cue cannot be matched to any further stimuli in memory, it is proposed that the cue returns to context once again and the generation of new stimuli from memory begins afresh (Shiffrin, 2003). When emotional and neutral stimuli are presented intermixed,

it is suggested that the emotional context is dominant; probably due to the inherent salience of these stimuli (Vuilleumier, 2005), which attract attention and receive more stimulus elaboration. Therefore if a mixed list of emotional and neutral stimuli are encoded in light of the dominant context: emotion; this would render neutral stimuli more difficult to recall due to the inaccessibility of an appropriate match between the context cue and stimulus information (echoing the notion of atypicality).

To summarise, distinctiveness is a psychological construct with a somewhat circular definition: distinctiveness processing is used to explain better memory, and memory has been used as a measure of the magnitude of distinctiveness processing. The definition of distinctiveness processing that we test here essentially breaks down this process into item-specific and relational processing (according to the definition of Hunt & McDaniel, 1993), which could be thought of as the processing of common and non-common properties amongst the stimuli of a list. Although a wealth of convergent evidence supports the mnemonic benefit of distinctiveness processing on memory (Einstein & Hunt, 1980; Epstein et al., 1975; Hunt & Einstein, 1981), little is known about whether the mechanism and outcome of distinctiveness processing would be consistent with these reviewed findings when the category identifier is emotion (negatively valenced arousing stimuli versus neutral non-arousing stimuli).

6.1.3. Experimental aims and hypotheses

Replicating our previous work, we used stimuli taken from SeRENS (Semantically related emotional and neutral stimuli; see Barnacle, Madan & Talmi, *in prep.*) which were controlled for semantic relatedness, and objective visual complexity. We had

previously suggested that the difference in EEM between pure and mixed lists was due to distinctiveness processing (Talmi, Luk, et al., 2007), but the behavioural experiments to date have not characterised the mechanism of distinctiveness processing (i.e. as fitting with the definition by Hunt and McDaniel, 1993 or otherwise). In order to better characterise distinctiveness processing and its contribution to the EEM, we chose to test the premise of distinctiveness processing by breaking down the mechanism upon which the definition is predicated (item-specific and relational processing). We therefore tested the memory of emotional and neutral stimuli in pure and mixed encoding lists (list type manipulation; mixed lists said to invoke distinctiveness processing) in three different groups of participants with different encoding instructions. The instructions for each group targeted a specific facet of distinctiveness processing (item-specific or relational processing), or involved 'natural' encoding where no instructions were given, replicating our previous work.

For the item-specific task we chose to deviate from previously used orienting tasks (Einstein & Hunt, 1980; Hunt & Einstein, 1981) which used a pleasantness rating. This is due to the obvious confound that emotional pictures would on average be considered less pleasant than neutral pictures; meaning that there would likely be significant differences in the ratings of emotional and neutral stimuli, which could be confounding to our investigation. Another difficulty of using a pleasantness task was that – although intended as an item-specific task – because the stimuli could be effectively divided into pleasant / unpleasant categories, this could enable participants to make mental links between stimuli of the same pleasantness rating; thus not representing a purely item-specific processing task. Instead, we developed an orienting task which would not encourage semantic links between the pictures,

was difficult enough to fully engage the participant, and one for which the rating responses would be varied and not significantly different according to the valence of the stimulus. For this item-specific task we instructed participants to rate the location of the main action or information in the picture; henceforth termed the “ITEM” group (see procedure for more detailed information).

For the relational task, we maintained the idea of a categorical sorting task but adapted the task to be presented on a computer (in the studies of Hunt and colleagues, stimuli were printed on cards and physically placed into a category pile). Instead we used a task developed for a previous study (Barnacle, Madan & Talmi, *in prep.*), which we were confident would be easily adopted by participants, and which required relational processing. For this relational task we instructed participants to rate the semantic relatedness of a target stimulus to a set of themed examples; henceforth referred to as the “RELATE” group. Crucially, participants were instructed to complete their relatedness judgement in the relational task based on the meaning of the stimuli (not low level properties e.g. colour), thus representing a semantic processing task (see procedure for more detailed information).

Importantly, each task was designed to be sufficiently taxing such that processing of stimuli in each of the ITEM and RELATE groups would be mutually exclusive (i.e. extra processing resources should not be available for additional item-specific processing in the relational processing condition, and vice versa) in so far as is possible. We also tested memory in a group where no orienting task was instructed. This was therefore the same paradigm as used in previous studies of our lab, and represented a baseline condition against which the results of the experimental groups ITEM and RELATE could be compared. This group is therefore referred to as the “baseline” condition.

According to the reviewed literature, we have developed several testable predictions to determine whether the mechanism of distinctiveness processing (as defined here) is upheld when stimulus categories are defined as emotional and neutral stimuli. If the results obtained are not consistent with these predictions, this would suggest either that emotion as a category has a special status in relation to distinctiveness processing; or that distinctiveness processing cannot in fact be reduced to the mechanisms of item-specific and relational processing – a question considered in the discussion of the current results.

Our predictions were as follows: 1) In accordance with historical findings (Einstein & Hunt, 1980; Epstein et al., 1975; Hunt & Einstein, 1981), we hypothesised that the relational task ('RELATE') would not further improve memory for any category of stimuli (emotional or neutral) presented in any kind of list (mixed / pure) because the within-set semantic relatedness of all stimuli used in this experiment was high. Based on this same evidence we also hypothesised that the item-specific task ('ITEM') would universally increase memory for all types of stimuli (emotional or neutral) in both kinds of list.

We also tested an alternative prediction based on our previous neuroimaging results. Given that these prior results demonstrated an association between less neural activity in semantic processing brain regions and a deficit in mixed neutral memory (relative to pure neutral memory, and emotional memory) we also predicted that 2) the memory of neutral stimuli in mixed lists would benefit in the RELATE condition (which encourages semantic processing). If we concede that neutral stimuli in mixed lists could indeed suffer a deficit of semantic processing then this prediction also follows from the work of Hunt & Einstein (1981), which would therefore categorise mixed neutral stimuli as atypical; and MacKay et al. (2004) which suggests

that neutral stimuli have a relative deficit in stimulus-context binding. According to both studies, encouraging semantic processing should improve memory for such stimuli.

We also tested one final alternative prediction based on the reviewed literature and our previous findings implicating the ventral attention network in the EEM effect. Given that it is suggested that top-down processing could filter reflexive signals from bottom-up attention (Fox et al., 2006); and given the evidence that intentional, goal-driven (top-down) processing has been shown to reduce the subjective experience of emotion, and emotional processing in the brain (Adenauer et al., 2011; Grimm et al., 2012), we also predicted: 3) Mixed list emotional memory would be reduced under any conditions employing a goal-directed, intentional orienting task, which we supposed would increase top-down processing (e.g. both ITEM and RELATE), relative to conditions where no specific orienting task was instructed (baseline).

6.2. Methods

6.2.1. Participants

We recruited 53 participants (19 male, mean age = 24 years), who were students and Staff at the University of Manchester, and who were randomly allocated to one of three groups upon recruitment (RELATE $n = 21$, ITEM $n = 16$, baseline $n = 16$). A power analysis was conducted using G*Power, to determine how many participants would be required to detect a significant EEM effect given semantically related stimuli. Using the effect size (Cohen's $d = 0.97$) reported in Talmi et al. (2007) power analysis indicated that each condition of the experiment would require a total

number of 16 participants, in order to identify a significant effect. We did not have previous data to conduct a power analysis for the between groups effects.

This experiment was approved by the University of Manchester Research Ethics Committee and employed the same distress policy procedure (available upon request) as in Barnacle, Madan and Talmi (*in prep*); see reference for details. Part of the distress policy involved asking participants to rate their mood before and after the experiment on four scales from Bored to Engaged, Unhappy to Happy, Anxious to Calm, and Miserable to Cheerful. This was used for monitoring purposes only and was not analysed. Participants provided informed consent and were reimbursed for their time and expenses.

6.2.2. Materials

The experimental stimuli (those pictures which were the target of memory for participants) comprised 48 emotional-, 48 neutral colour pictures taken from SeRENS (Barnacle, Madan, & Talmi, *in prep.*) and were supplemented by IAPS (Lang, Bradley & Cuthbert, 1997; 2008; images: [3266, 3120, 2800, 9253, 9250, 3102, 3550, 9420, 3500, 6550, 3015]). Stimuli were 280 x 210 pixels in size (IAPS were resized maintaining the aspect ratio using Irfanview 4.23). Emotional pictures were negatively valenced and arousing, and neutral pictures were neither positive nor negative in valence and low on arousal measures. In addition, the emotional and neutral sets were matched for within-set semantic relatedness and visual complexity (see Table 6.1 for average scores per stimuli set; see Barnacle, Madan & Talmi, *in prep.*, for methods). Stimuli were randomly allocated to blocks of the experiment, and presented in a random order within each block. Each block contained either all

neutral (“pure neutral lists”), all emotional (“pure emotional lists”), or an equal number of emotional and neutral pictures (“mixed lists”). The first two stimuli of each block were buffer images and as such were removed from all analysis (reducing primacy effects). Participants in each group of the experiment viewed these same experimental pictures for the experiment trials; however the pictures presented in the practice block were dependent on the group of the experiment in which the participant was placed. The practice block stimuli were designed to be different in nature to the stimuli of the main experiment (i.e. different semantic themes), so that priming and practice effects were reduced.

Table 6.1. Stimulus properties

	Emotional	Neutral
Arousal**	6.19 (0.61)	2.37 (0.23)
Valence**	2.50 (0.43)	5.44 (0.35)
Semantic relatedness	5.10 (0.44)	5.00 (0.46)
Visual Complexity: Edge Density	0.07 (0.02)	0.06 (0.02)
Visual Complexity: Feature Congestion	4.66 (1.24)	5.07 (1.18)
Visual Complexity: Subband Entropy	3.09 (0.22)	3.06 (0.14)

Each participant contributed a mean rating score for each measure, calculated as the average score across all stimuli of each category (emotional / neutral). Data here is the grand average across all participants. Standard deviation presented in parentheses.

*** indicates significant difference between emotional and neutral stimuli at $p < .001$. Both arousal and valence measures were rated on a scale 1-9 (as per SAM scale, Bradley & Lang, 1994); semantic relatedness was scored on a scale of 1-7, 1 = low, 7 = high relatedness. Measures of objective visual complexity were computed using MATLAB code from (Rosenholtz et al., 2007); see Barnacle, Madan & Talmi (in prep) for more details.*

The stimuli presented in the practice block of the ITEM task were 14 pictures of sports taken from IAPS (Lang, Bradley & Cuthbert, 1997; 2008; images [8312, 8032, 8060, 8117, 8118, 8121, 8021, 8250, 5626, 8160, 8185, 5628, 4535, 4533])

presented in a random order. Sports pictures were used here because the item-specific task requires participants to locate the 'action' of the picture (see procedure below for detailed instructions), and the topic of sports provided obvious examples of this. The experimental stimuli presented in the practice block of the RELATE and baseline conditions were of foods and sports (7 of each, taken from IAPS, Lang, Bradley & Cuthbert, 1997; 2008; numbers food: [7281, 7287, 7290, 7300, 7350, 7461, 7477]; sports: [8312, 8032, 8060, 8117, 8118, 8121, 8021]), presented in a randomised order.

In addition to the experimental pictures, in the RELATE condition participants were also presented with two matrices of pictures which represented a theme against which they were asked to make their relatedness rating (see procedure below for details). In the practice block the matrices represented 'water sports' and 'sugary snacks' (water sports IAPS: [8041, 8080, 8200, 8208, 8370, 8420]; sugary snacks IAPS: [7270, 7390, 7405, 7410, 7430, 7470]) and in the main experiment the matrices represented 'violent crime' and 'home leisure activities' (taken from SeRENS, Barnacle, Madan & Talmi, *in prep.*). Each matrix was a 2 x 3 grid of pictures resized to 395 x 613 pixels, presented on the left and right of the screen (counterbalanced across participants).

To control for visual presentation across groups, in the ITEM and baseline groups the same matrices were presented to participants in the same location as the RELATE group, but in scrambled form. Matrices were scrambled using MATLAB: we recorded the RGB (red, green, blue) values for each pixel from the RELATE matrices, and relocated those values per pixel to another location in the matrix (programmed in MATLAB), thereby matching for visual presentation across group. Stimulus

presentation was programmed using Cogent Graphics on a MATLAB platform, and presented visually on a computer monitor approximately 50cm from the participant.

In all conditions participants recorded their free recall responses by hand in a free recall response booklet. The booklet contained an example of acceptable free recall responses on the first page (which was highlighted to participants during the instructions phase), and a page for each of the subsequent blocks of the experiment (9 more pages, including the practice block page).

6.2.3. Procedure

For clarity, procedural details of paradigm tasks are described here in the order in which they occurred. Within the description of each task, procedural details common to all groups are described first; and group-specific caveats (as per ITEM, RELATE, baseline) described after.

For all groups each block of the experiment consisted of three tasks: list encoding, distractor, and free recall; and each participant underwent 9 blocks of the experiment (including one practice block), following the procedure of previous work (Barnacle, Tsivilis, Schaefer & Talmi, *in prep.*; Barnacle, Montaldi, Talmi & Sommer, *in prep.*).

During the instructions phase, the instructions for all tasks, according to group, were presented visually and read aloud by the experimenter to each participant before testing began. The instructions introduced each task with a description first, followed by an example of what the participant would see on screen during a given task (encoding, distractor, free recall). When the instructions described the free recall task, participants were additionally asked to familiarise

themselves with the layout of the recall response booklet, and example answers. Participants were encouraged to ask questions throughout the instructions phase. Following the instructions phase, participants took part in one practice block. After the practice of the free recall task, the experimenter and participant reviewed the participant's recall responses together, and feedback was provided by the experimenter regarding the level of detail provided, the use of the recall response booklet, and the legibility of the participant's handwriting as necessary. After the practice block all participants were given the opportunity to ask any more questions, and they then proceeded to the experimental blocks.

6.2.3.1. List encoding

Before each block of the experiment all participants were presented with a message which reliably informed them about the nature of the stimuli they would see in that block ('All neutral images', 'All emotional images', or 'A mixture of emotional and neutral images').

Additionally, in the RELATE group participants were also presented with the two matrices at the beginning of each block, and were asked to decide what they believed the theme of each matrix was. Participants were given as much time as they required for this, and were not asked to state what they believed the theme was. We did not require that each participant's interpretation of the theme to be the same, as long as participants could draw on their interpretation to complete the relational task. The content of the matrices according to the experimental group remained the same throughout all blocks of the experiment.

During the list encoding task, all participants encoded 14 images per block under intentional encoding instructions. The trial stimulus was presented in the centre of the screen, and the corresponding matrices (as described above) were presented on the left and right of the screen. The matrices remained on screen throughout the list encoding task. Participants in the ITEM and baseline groups were advised that the matrices (which were scrambled in these conditions) were not to be used, and therefore that they could ignore the matrices entirely.

Before each stimulus presentation a fixation cross was presented for 500ms, which served to alert the participant to the imminent presentation of a new stimulus. Each image was presented for 2000ms as per previous work (Barnacle, Tsivilis, Schaefer & Talmi, *in prep.*; Barnacle, Montaldi, Talmi & Sommer, *in prep.*). After stimulus offset participants were presented with a scale according to the group in which they were placed. The scale remained on the screen for 4000ms (same inter-stimulus interval as used in our previous studies) regardless of the latency of participant response. We reasoned that a consistent amount of time for the scale presentation regardless of response latency would encourage careful processing of the task decision, and discourage rushing to make a response. The scales in each group were presented in the same location (centre of screen), and had the same number of intervals so as to match the visual presentation and complexity across groups. The scale was specifically designed to have an even number of intervals (4 intervals), which we thought would discourage repetitive mid-scale responses, which participants often mistake for a 'don't know' option.

Participants in the ITEM group were instructed to rate the location of the main action or information in the stimulus they saw on a scale of 1 – 4 (1 = far left, 2 = mid-left, 3 = mid-right, 4 = far right). The participant made their responses by choosing

from 4 keys on the keyboard which were labelled 1-4 with coloured stickers (keys FGHJ). This 1-4 scale was particularly useful for the ITEM group because it forced participants to choose between left and right (no scale interval to indicate a judgement that the action was in the centre of the screen); whereas objectively the actions of many of the stimuli were in the centre of the picture. We reasoned that this would encourage careful processing of the stimuli, increasing the level of difficulty for this task. To ensure that there were no significant differences between the proportion left/right ratings between emotional and neutral stimuli a pilot study of 10 independent participants rated the stimuli used in this experiment. Results revealed that there was no significant difference in the proportion of left/right responses to emotional compared to neutral stimuli; $t(9) = 1.07, p = .31$.

Participants in the RELATE group were instructed to rate the relatedness of the trial image to the corresponding matrix on a scale of 1 - 4 (1 = low relatedness, 4 = high relatedness) using the same keys on the keyboard for their responses. The appropriate matrix was determined by the category membership of the trial stimulus, and was highlighted with a yellow border coincident with stimulus onset. For example, if an emotional picture was presented as the trial picture, the corresponding emotional matrix ('violent crime') was highlighted. Participants were instructed to rate the trial stimulus in relation to the highlighted matrix, and to make their relatedness judgement based on the level of shared *meaning* between the trial and example matrix, and not based on low level similarities such as colours or the presence of objects. This was particularly important as we wanted to this task to embody semantic processing. Participants were instructed to fixate on the trial picture throughout the whole duration of presentation so as to avoid their being distracted by looking at the corresponding matrix, which might disadvantage their

encoding compared to other conditions. Participants were free to look at the matrices after stimulus offset (during rating response time) and at the beginning of each block of the experiment. To avoid confusion, the location of the matrices was not randomised (left/right) across the blocks of the experiment, but matrix location was randomised across participants.

Participants in the baseline group were not required to make any response, and therefore a nonsense scale was presented at the same time and location as in the other groups to match for visual presentation. The scale had four intervals (as in the conditions described above), and the left most interval of the scale was arbitrarily labelled 'low', and the right most interval labelled 'high', with 'X's presented below instead of numbers 1-4. Participants were told that this scale was not to be used, and that they did not need to make any response, and therefore could ignore the scale.

After the offset of the scale, the fixation cross appeared again indicating the imminent presentation of the next trial. List encoding proceeded in this fashion for a total of 14 trials per block; after which the distractor task ensued.

6.2.3.2. Distractor task

The distractor task was the same for participants in all groups. The task, described briefly here, was identical to that of Barnacle, Tsivilis, Schaefer and Talmi (*in prep.*); and Barnacle, Montaldi, Talmi and Sommer (*in prep.*). Two simple sums were presented, one each on the right and left hand side of the screen. Participants were asked to compute the sums mentally and identify the highest value sum using two keys relating to the right or the left of the screen (the right or left arrow key). After their response two new sums were presented, and this continued for the duration of

the task (60 seconds). Participants were instructed to solve as many problems as possible, to be as accurate as possible, and that their responses would be checked. After 60 seconds the free recall task ensued.

6.2.3.3. Free recall task

The free recall task was the same for participants in all groups. This task was indicated by the visual presentation of the words “free recall” on the computer screen. Participants were instructed to recall as many trial images from the encoding list as they could remember, in any order and in as much detail as possible; by writing descriptions of the stimuli in the recall response booklet. Participants were asked to be specific in their descriptions of stimuli, and that descriptions of two similar images should be distinguishable from their responses. In particular participants were advised on a basic level of acceptable detail – at a minimum, participants were instructed to include in their answer: 1) *who* was in the picture; 2) *what* were they doing; and 3) *where* were they? Participants were also encouraged to note any outstanding details that they could remember that may not fall under these three descriptors. It was made clear to participants that they should include as much detail as possible in their responses, as some pictures were very similar, and this detail would be useful in determining a remembered picture from a similar forgotten picture. Participants were given 3 minutes for this task (recall time determined pro-rata based on the timing of Dolcos & Cabeza, 2002; and conforming to Barnacle, Tsivilis, Schaefer and Talmi, *in prep.*; and Barnacle, Montaldi, Talmi and Sommer, *in*

prep.). Participants endured the whole 3 minutes for this task even if they had stopped actively recalling before this time so as to encourage further recall, and to control for differences in motivation levels across participants. After 3 minutes a screen was presented to alert the participant to the end of that block. The screen comprised a large red stop sign (akin to that seen when driving), accompanied by instructions to stop writing and continue to the next block of the experiment (self-paced by button press).

The tasks proceeded as described here for a total of eight experimental blocks, after which participants were debriefed and paid. For a graphical representation of the task procedures per group see Figure 6.1.

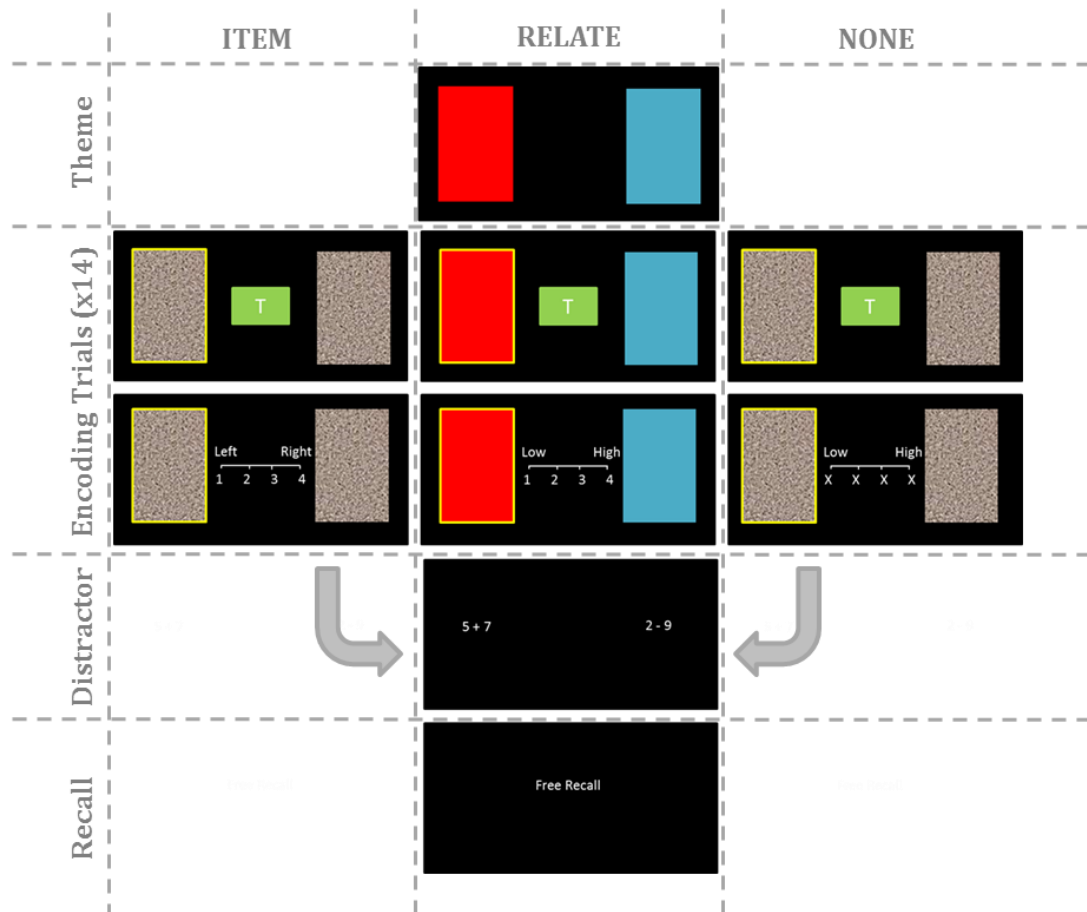


Figure 6.1. Schematic of all paradigm tasks according to group

In the RELATE group (middle column) participants were first asked to identify a theme for each of the example matrices (red/blue rectangles). All groups then underwent 14 trials per block with their associated orienting task (ITEM = left/right judgement; RELATE = low/high relational judgement; baseline = no judgement). All groups then took part in the distractor and free recall tasks.

6.3. Analysis

In order to test whether the EEM effect was altered by encoding instructions based on distinctiveness processing, we planned to conduct independent samples t-tests comparing the mixed and pure list EEM effect in the ITEM compared to baseline groups, and the RELATE compared to baseline groups. In order to calculate the EEM effect we first calculated proportion recalled scores for all conditions (mixed emotional, mixed neutral, pure emotional, pure neutral), which were calculated as the

number of recalled stimuli of that condition divided by the total number of stimuli seen in that condition (e.g. number of recalled mixed list emotional stimuli divided by the total number of mixed list emotional stimuli presented). The EEM effect was then calculated by subtracting the proportion recalled neutral from the proportion recalled emotional of each list type (mixed, pure). If this analysis revealed significant differences we planned to follow up with further planned t-tests, to determine whether the between group difference in EEM was due to an increase or decrease in memory for emotional or neutral stimuli (or a combination). Due to the large array of data collected in this experiment, and due to our very specific predictions generated based on previous literature and our own previous results, there was a clear rationale for our analysis to be comprised predominantly of planned t-tests. We did however also conduct a mixed ANOVA which can be found in Appendix B.

Participants in the experimental groups (ITEM, RELATE) rated each trial stimulus according to their instructions (ITEM: action left/right of screen; RELATE: relatedness to corresponding matrix). We excluded from further analysis any participant who failed to provide ratings for one or more whole block of the experiment (i.e. of 14 trials, 0 ratings were made); and this criteria resulted in the exclusion of one participant. We also excluded participants if they missed more than 20% of the ratings over all trials (>22.4 trials missed out of 112); and this criteria resulted in the exclusion of a further 3 participants. This left a total of 19 participants in the RELATE group, 15 participants in the ITEM group, and 16 participants in the baseline group. The removal of these participants was important when comparing between groups because we needed to be confident that the participant had engaged in the task sufficiently to include their data as part of the encoding instruction manipulation. Overall the number of missed trials was low (after removal of the

excluded participants as per above): in the ITEM group on average participants missed a total of 3.73 trial ratings; and in the RELATE group on average participants missed a total of 3.67 trial ratings.

6.4. Results

6.4.1. Inter-rater reliability

Two independent experimenters coded the free recall responses. When written responses of free recall were successfully matched to the stimuli seen in each block, this determined the recall status of the stimulus as 'recalled'. Stimuli that did not have a corresponding description in the free recall responses were coded as 'forgotten'. Recall descriptions which matched a stimulus that was seen in a previous block were coded as intrusions and were not analysed further. Reasonable errors in the recall descriptions were allowed – for example if a female was described as a male but the other details of the description were accurate; or if a baby was described as a child or vice versa (which we considered to be ambiguous terms that vary between people). The coding of all participants' recall responses was compared between raters and disagreements resolved through discussion. Generally the recall descriptions were rich in detail (we think due to the instructions which asked participants to provide as much detail as possible, and owing to the feedback provided on this during the practice block), and as such inter-rater reliability was high – 99%.

6.4.2. Between-group differences

We first wanted to test if the current results in the baseline group replicated previous results – no pure list EEM, a significant mixed list EEM driven by a reduction in neutral stimulus memory compared to pure lists (e.g. Talmi et al., 2007). We conducted a repeated measures ANOVA for the baseline group comparing the proportion recalled scores using list type and valence as factors. This analysis revealed a significant interaction ($F(1,15) = 7.48, p = .02, \eta^2 = 0.33$), but no significant main effects (both $p > .05$). In order to better understand this interaction we conducted four Tukey HSD corrected post-hoc paired sample t-tests, using proportion recalled as the dependent variable. Results largely replicated previous findings: we identified a significant mixed list EEM $t(14) = 2.66, p = .02$, Cohen's $d_z = 0.67$ (significant when controlled for multiple comparisons); but no significant pure list EEM $t < 1$. The mixed list EEM effect was driven by a significant decrease in memory for neutral stimuli compared to pure lists $t(14) = -2.34, p = .03$, Cohen's $d_z = -0.59$; and we additionally found that memory for mixed list emotional stimuli was increased relative to pure lists $t(15) = 2.48, p = .03$, Cohen's $d_z = 0.62$; however neither of these two comparisons remained significant when controlled for multiple comparisons. For proportion recalled data of the baseline and experimental groups see Figure 6.2.

In order to investigate if the EEM effect had been affected in the experimental groups (ITEM, RELATE) compared to the baseline group, we conducted 4 planned independent samples t-tests (mixed lists: ITEM_{EEM} vs. baseline_{EEM}, mixed lists RELATE_{EEM} vs. baseline_{EEM}; pure lists: ITEM_{EEM} vs. baseline_{EEM}, pure lists: RELATE_{EEM} vs. baseline_{EEM}) using the calculated EEM as the dependent variable. Firstly we wanted to investigate whether there were significant differences for mixed list memory. We found that the mixed list ITEM_{EEM} was significantly larger than the mixed list baseline_{EEM}: $t(29) = 2.44, p = .021$, Cohen's $d_s = 0.88$; but that mixed list

RELATE_{EEM} and baseline_{EEM} were not significantly different: $t(32) = 0.07, p = .942$, Cohen's $d_s = 0.03$. For the pure list conditions we found that the difference between pure list ITEM_{EEM} and baseline_{EEM} approached significance: $t(29) = 2.03, p = .051$, Cohen's $d_s = 0.73$; whereas the pure list RELATE_{EEM} and pure list baseline_{EEM} were not significantly different: $t(32) = 0.95, p = .348$, Cohen's $d_s = 0.33$; see figure 6.3. As we already knew that the pure list baseline_{EEM} was not significant following our initial investigation of these baseline group data, we wanted to test whether the significant difference between baseline_{EEM} and that of pure list ITEM_{EEM} was driven by a significant pure list ITEM_{EEM}. A post-hoc paired samples t-test investigating proportion pure emotional compared to neutral recalled was carried out for the ITEM group data, and revealed a non-significant trend, $t(14) = 1.85, p = .08$, Cohen's $d_s = 0.49$.

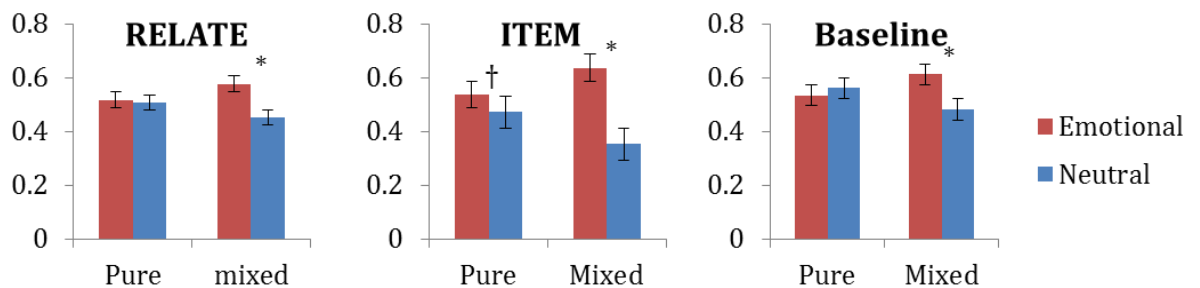


Figure 6.2. Proportion recalled per condition and group

*Each plot represents the proportion recalled score (y axes) for all conditions for one group as labelled in the graph title. * indicates significant difference at $p < .05$, † indicates non-significant trend.*

It is clear that these results alone cannot determine whether between-group differences in the EEM effect are due to changes in memory for emotional or neutral stimuli (or both), which might be important for our interpretation of these results.

Therefore for each significant result, we carried out two further planned independent samples t-tests. For the mixed lists, we found that the significant difference between $ITEM_{EEM}$ and $baseline_{EEM}$ was driven by a significant decrease in neutral memory in the ITEM compared to baseline group, $t(29) = 2.83, p = .008$, Cohen's $d_s = 1.02$; whereas the proportion recalled for mixed emotional stimuli did not vary statistically between the two groups, $t(29) = 0.51, p = .61$, Cohen's $d_s = 0.18$. For the pure lists, we found that the difference between the $ITEM_{EEM}$ and $baseline_{EEM}$ was driven by a reduction in neutral memory in the ITEM compared to baseline group, although this was a non-significant trend: $t(29) = 1.97, p = .059$, Cohen's $d_s = 0.71$. Memory for emotional stimuli did not vary statistically between the two groups, $t(29) = 0.05, p = .963$, Cohen's $d_s = 0.02$.

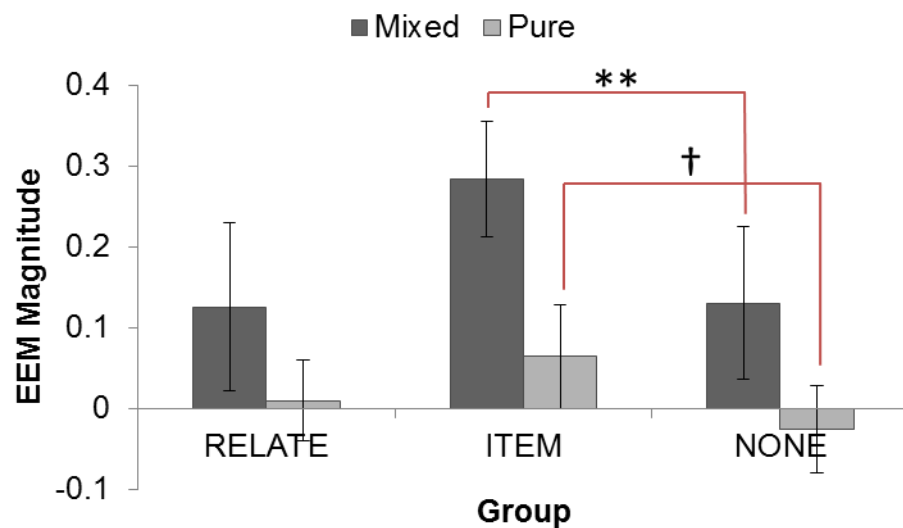


Figure 6.3. Graphical representation of EEM effects for pure and mixed lists

The EEM effect relates to the difference between the proportion emotional recalled and proportion neutral recalled. EEM effects from RELATE and ITEM groups were compared to the baseline group. Error bars denote standard error of the mean. Where error bars overlap the x axis, the EEM is not significant. Red lines indicate contrasts were

*significant at $p < .05$ (**), or where contrasts show a non-significant trend (+).*

Given that the significant differences identified between the mixed list EEM effect in the ITEM and baseline conditions were driven by a reduction in neutral memory, we were curious to see if this was due to between-group differences in retroactive emotional interference acting on neutral memory. This seemed a logical hypothesis given that previous research has evidenced such a phenomenon (e.g. Hurlemann et al., 2007). We therefore conducted an exploratory independent samples t-test to compare the proportion forgotten neutral stimuli that were presented before an emotional stimulus (E-1) for the ITEM group compared to the baseline group. To achieve this, for each participant we counted the number of forgotten neutral trials that were presented before an emotional trial, and divided this number by the total number of neutral trials presented before an emotional trial. A comparison of this measure between the ITEM and baseline groups confirmed that there was a higher proportion of forgotten E-1 stimuli in the ITEM compared to the baseline group ($M = .65$, $SD = 0.17$; $M = .51$, $SD = 0.14$ respectively), and that this difference was statistically significant; $t(29) = 2.57$, $p < .05$, Cohen's $d_s = 0.92$. In order to verify that this effect was specific to the ITEM group and not an artefact of instructed encoding per se, we conducted the same analysis comparing the RELATE to baseline group; which confirmed that this result was not significant ($t < 1$).

6.5. Discussion

6.5.1. Replication of previous results – baseline group

We set out to examine whether the EEM effect could be altered given different encoding instructions which ‘tapped’ two facets of distinctiveness processing – item-specific processing, and relational processing (Hunt & McDaniel, 1993). In order to make justifiable comparisons between the experimental groups: ITEM and RELATE, with the baseline group, we first analysed the baseline group for evidence of a mixed-list EEM effect driven by a significant reduction in neutral memory in mixed compared to pure lists. It was important that the pattern of results in this group replicated previous results (Barnacle, Tsivilis, Schaefer & Talmi, *in prep.*; Barnacle, Montaldi, Talmi & Sommer, *in prep.*; Talmi et al., 2007; Talmi & McGarry, 2012) as the current experiment aimed to explain this specific pattern of EEM, which we previously interpreted as an effect of distinctiveness processing. The results from the baseline group did replicate previous results, thus confirming that the adaptations made in this experiment compared to previous experiments (screen layout during stimulus presentation, scale presented during inter-stimulus interval [ISI]) did not unduly alter the pattern of EEM.

6.5.2. Relational processing confers no extra mnemonic benefit for already semantically related stimuli

Our review of the literature led us to 3 specific hypotheses that we assumed would hold true if distinctiveness processing did in fact occur in mixed lists of emotional and neutral stimuli, and if emotion as a category did not interact with the process of distinctiveness processing. Based on these assumptions we first hypothesised that given the high within-set semantic relatedness of the stimuli used here, the RELATE task would not prove beneficial to memory. This hypothesis was confirmed: memory performance in all conditions was not statistically different between the RELATE and

baseline groups (consistent with Einstein & Hunt, 1980; Epstein et al., 1975; Hunt & Einstein, 1981). Both groups produced comparable mixed-list EEM effects, and both groups produced no significant pure-list EEM effects. This null result suggests that participants in the baseline group (and previous matched paradigms) naturally carried out relational processing, noticing common properties and semantic links between the stimuli of an encoding list. This interpretation is supported by neuroimaging findings that evidence greater activation of semantic processing areas (e.g. anterior temporal lobes; Olson, McCoy, Klobusicky, & Ross, 2013; Visser, Jefferies, & Lambon Ralph, 2009; Barnacle, Montaldi, Talmi & Sommer, *in prep.*) during encoding of mixed emotional compared to neutral stimuli which was predictive of successful memory.

6.5.3. Lack of relational processing is detrimental for neutral memory

We also hypothesised that item-specific processing of our already semantically related stimuli would improve memory universally, irrespective of emotion and list-type. However, the data suggested that item-specific processing did not improve memory for any stimulus type in any condition; rather it universally decreased memory of neutral stimuli in both mixed and pure lists, without affecting memory for emotional stimuli. When comparing the EEM between the ITEM and baseline groups we found differences in both the pure and mixed list EEMs. Item-specific processing increased the difference between the proportion emotional and neutral recalled in the ITEM group compared to the baseline group (although the ITEM group pure EEM effect was not significant in itself). The EEM effects present in the ITEM group were increased relative to baseline because memory for neutral stimuli was reduced in the

ITEM group, an effect which was stronger in mixed lists. This would seem counterintuitive based on the evidence from the reviewed literature (Einstein & Hunt, 1980; Epstein et al., 1975; Hunt & Einstein, 1981) which states that item-specific processing for already related stimuli should be beneficial to memory. However, both findings (for pure and mixed-list EEM between-group comparisons) can be explained in light of the specific orienting tasks of the current paradigm, which were designed to induce item-specific *or* relational processing, but importantly, not to allow both to occur (in so far as was possible). Therefore, we suggest that in performing item-specific processing, this reduced (or *effectively* eliminated) any naturally occurring relational processing. We can foresee two plausible explanations of how this explains the current results: 1) Relational processing was effectively eliminated for both emotional and neutral stimuli in the ITEM group; however this did not affect the memory of emotional stimuli because they are additionally supported by another non-distinctiveness processing mechanism (e.g. salience, Corbetta et al., 2008; Vuilleumier, 2005). Or 2) During the ITEM task, relational processing was effectively eliminated for neutral but not for emotional stimuli; therefore memory for emotional stimuli was not affected. The latter suggestion seemed less likely given that we assumed that participants engaged in the orienting task to the same degree regardless of the stimulus valence.

6.5.4. Relational processing as a protective mnemonic strategy for mixed neutral stimuli

This leads us to our alternative prediction regarding the relational task: If the significant mixed list EEM effect was indeed caused by a lack of semantic processing

for mixed list neutral stimuli, we expected that *increasing* semantic processing using the relational task should increase the memory of these stimuli, thus reducing the mixed list EEM. We expected that we could verify the importance of relational processing to mixed neutral memory by showing that increasing relational processing would increase mixed neutral memory. However, support for the conclusion that relational processing was important to mixed neutral memory came in another guise: the orienting task that eliminated relational processing (ITEM) instead resulted in a decrease of neutral memory. Thus our results still demonstrated the importance of relational processing to mixed neutral memory, but from an opposite perspective.

Given that (as stated above) we believe that participants engaged in the orienting tasks equally for emotional and neutral stimuli, it follows that relational processing was eliminated for both emotional and neutral stimuli. This suggests that eliminating relational processing was only detrimental for neutral stimuli and that emotional stimuli may be resistant to the effects of eliminating relational processing – possibly due to the additional salience of emotional stimuli (Corbetta et al., 2008; Vuilleumier, 2005). This implies that during ‘free’ encoding (baseline group and previous experiments with no encoding instructions) semantic relational processing is a somewhat effective protective mechanism against the already apparent detriment to mixed neutral memory. That is to say that when relational processing does occur in RELATE and baseline groups, a detriment to mixed neutral memory still exists, but the detriment is larger when no relational processing occurs (e.g. in the ITEM group). To understand the process by which the detriment to mixed neutral memory naturally occurs we look to our data on the retroactive interference of emotional stimuli on neutral memory.

When we compared the incidence of forgotten neutral stimuli we found that the incidence of forgotten E-1 stimuli was greater in the ITEM group when relational processing was eliminated, compared to the baseline group where we assumed relational processing was occurring. Based on this evidence, we posit that the onset of an emotional stimulus after a preceding neutral stimulus may be disruptive to neutral stimulus encoding, which is usually protected by semantic processing (in the baseline group, and previous paradigms). Conversely encoding of an emotional stimulus preceded by a fellow-emotional stimulus can continue (and may even be beneficial) because of their shared categorical status and mutual salience, see figure 6.4. Indeed it is common knowledge that an encoding trace takes an appreciable time to stabilize as an episodic memory, and that this may be disrupted e.g. by distractions from other stimuli (Dudai, 2004). Additionally, many studies show that emotional stimuli receive greater post-stimulus elaboration (Schmidt & Saari, 2007; Watts et al., 2014); and corroborating evidence suggests that emotional stimuli can exert a retroactive interference on neutral stimuli (Hurlemann et al., 2007; Strange, Kroes, Roiser, Tan, & Dolan, 2008; Strange, Hurlemann, & Dolan, 2003). Additionally, post-stimulus distractors are said to retroactively interfere with memory of the preceding stimulus when the stimulus and distractor are unrelated (e.g. when an emotional stimulus follows a neutral stimulus), whereas memory of the target stimulus is enhanced when the stimulus and distractor are related (Oberauer, Farrell, Jarrold, Pasiiecznik, & Greaves, 2012). This may also have a knock-on effect at recall, because a deficit of neutral stimulus processing may result in a lack of context from which neutral stimuli could be self-cued during free recall (Shiffrin, 2003), consistent with binding theory (Hadley & MacKay, 2006; MacKay et al., 2004). Once again this reinforces the importance of relational processing as a contributor to memory, which when

effectively eliminated leads to a greater deficit in memory performance of neutral stimuli, but not emotional stimuli.

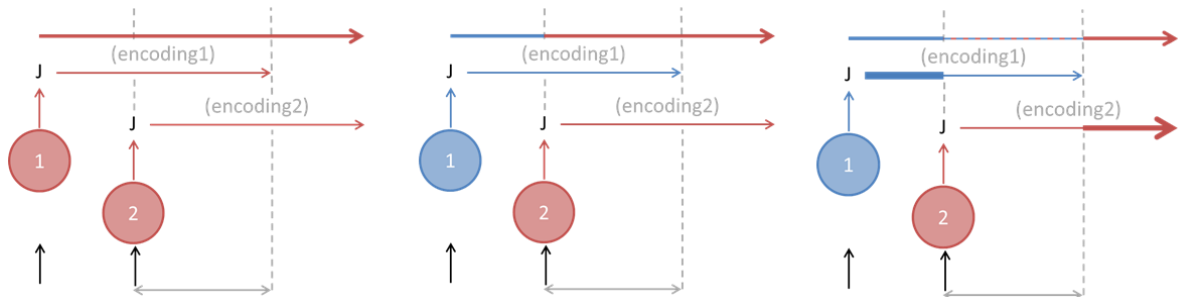


Figure 6.4. Graphical representations of retroactive interference mechanism according to list and group

LEFT: two successive emotional stimuli (labelled 1, 2) in a pure list. At the onset of the stimulus (denoted by the black arrow) the participant sees the emotional stimulus (red circle) and is prompted to make a judgment, according to the orienting task (J). Encoding processes begin at stimulus onset (thin red arrow). This repeats at the onset of the following stimulus, and processing overlaps between stimulus 1 and 2 (grey arrow and dashed lines). Overall encoding is not disturbed (bold red line, above). MIDDLE: Mixed-list processing in the ITEM group. In a mixed list where no relational processing occurs the same mechanism ensues, however when a neutral stimulus (blue) is followed by an emotional stimulus, the overlap in encoding processes causes a disturbance to neutral encoding (as demonstrated by the change in colour from blue to red of the bold line, above). RIGHT: Mixed-list processing in the baseline group. When a neutral stimulus is followed by an emotional stimulus, neutral encoding is initially strong (bold blue line); but weakens at the onset of an emotional stimulus. The relational processing assumed to occur allows concurrent neutral and emotional processing (blue and red dashed arrow section, above).

6.5.5. Top-down processing does not inhibit emotional encoding

Finally, we also hypothesised that by performing an orienting task such as those instructed within this paradigm (either item-specific or relational processing); one would invoke a top-down attentional strategy at the expense of reflexive bottom-up attention (Adenauer et al., 2011; Fox et al., 2006; Mathews, 2004; Uncapher et al.,

2011), said to occur with the presentation of emotional stimuli. Previous results suggested that one of the crucial processes that contributed to the mixed-list EEM was that of bottom up attention – the areas corresponding to which (e.g. supramarginal gyrus, [SMG]) showed greater activation for the encoding of mixed emotional compared to neutral stimuli, and mixed emotional compared to pure emotional stimuli (Barnacle, Montaldi, Talmi & Sommer, *in prep.*). However, the current results did not support this hypothesis – emotional memory was not significantly decreased relative to the baseline group despite encouraging greater top-down control. Our evidence could therefore be interpreted in several different ways: 1) item-specific processing did not reduce bottom-up processing (a) because experimental orienting tasks did not [sufficiently] induce a top-down attentional strategy, or (b) because top-down and bottom processing up are not in competition; 2) bottom-up processing was reduced but is not important for the mixed list EEM; 3) bottom up processing was reduced, but an alternative mnemonic mechanism was preferentially activated to aid emotional memory. Explanation 1a seems most harmonious: It is logical that exerting control over emotional processing – thought to be regulated by age-old evolutionarily preserved brain systems – would need practice and training before it could successfully be implemented (Mathews, 2004). Future studies could investigate whether changes in the EEM effect are apparent after more vigorous training on such top-down processing tasks.

6.6. Conclusions

In summary we have mixed evidence suggesting that distinctiveness processing as defined by Hunt & McDaniel (1993) contributes to the EEM effect. Increasing

relational processing did not improve memory relative to the baseline group; and likewise a reduction in the availability of item-specific processing resources in this group did not alter the EEM effect. When relational processing was effectively eliminated during directed item-specific processing, this negatively impacted the memory of neutral stimuli presented in both mixed and pure lists, thus increasing the EEM effects in this group relative to the baseline group. These results together suggest that relational/semantic processing is an important contributory factor to the list type x EEM results of our previous work, and is especially important for neutral stimuli. We propose that in conditions of free encoding with no orienting task (baseline, and previous work), mixed list neutral stimuli lack salience of emotional stimuli, which grab attention and processing resources away from mixed neutral stimuli; although this can be offset somewhat by relational processing. When this apparent lack of salience is compounded by specific instructions that eliminates relational processing (ITEM group), this is especially detrimental to neutral memory, even in pure lists. Crucially though, impairing the relational processing of emotional stimuli in the same manner did not reduce emotional memory, suggesting that other factors also contribute to the EEM effect (e.g. the salience of emotional stimuli). These results provide converging evidence that distinctiveness processing - defined as combinatorial item-specific and relational processing - does contribute to the list-type x EEM interaction. However, due to the fact that our data suggest that both kinds of processing were not equally important; we speculate that when emotion is the category identifier the interaction of distinctiveness processing and memory may represent a special case.

7. General Discussion

7.1. Summary of experimental programme

This thesis aimed to investigate the immediate emotional enhancement of memory (iEEM) effect, and the cognitive determinants of the same. To this end, four empirical studies were conducted. Due to the inherent differential within-set semantic relatedness of emotional and neutral stimuli, and given the evidence that this contributes significantly to the EEM, we sought to develop a stimulus set that could control this factor. This investigation led to the development of SeRENS: the Semantically Related Emotional and Neutral Stimuli set (chapter 3). Ratings scores of arousal, valence, and semantic relatedness taken from this investigation were used to verify stimulus selection for the subsequent EEG and fMRI studies (chapters 4 and 5); and the final experiment (chapter 6) utilised a subset of the final SeRENS stimuli (which also controlled for objective visual complexity). The EEG, fMRI, and final behavioural study employed the same (but adapted) paradigm to investigate memory of emotional and neutral stimuli presented in mixed lists (randomly intermixed emotional and neutral stimuli), and pure lists (only emotional or only neutral stimuli). The final behavioural experiment sought to examine the evidence for a contribution of distinctiveness processing (as defined by Hunt & McDaniel, 1993) to the EEM effect in mixed lists.

The discussion that follows will highlight the key findings from this research, and describes how these findings add new insights to our existing understanding of the EEM. The implications of this research for a unified model of the EEM effect will be discussed, along with recommendations for future work.

7.2. Summary of key findings and convergence across modalities

When semantic relatedness was controlled and no orienting task was present, behavioural data collected throughout this body of work consistently showed that there was a significant EEM effect under mixed list conditions but not in pure lists; which was driven by a significant decrease in neutral memory compared to pure list conditions. Replicating previous work (Talmi, Luk, et al., 2007; Talmi & McGarry, 2012), this positioned list-type (mixed versus pure lists) as a significant contributor to the EEM effect. By way of explanation, mediation theory (Talmi, 2013) cites distinctiveness processing as a contributory cognitive factor to the EEM effect in mixed lists; however the mechanism of how this process exerts its influence on encoding and subsequent memory was unknown. The current neuroimaging experiments aimed to better-characterise emotional and neutral encoding in mixed lists compared to pure lists; providing a neural characterisation of the contribution of such a distinctiveness processing mechanism to the EEM effect.

Three-way interaction analyses in both EEG and fMRI modalities (chapters 4 and 5) provided novel results regarding the involvement of cognition to the EEM effect (in addition to well-known memory and emotion effects), and crucial evidence that the immediate EEM is correlated with neural activity at encoding. The EEG data implicated the P300 and late positive potential (LPP) as the components through which distinctiveness processing exerts its influence on the EEM effect; and the fMRI data implicated the right supramarginal gyrus (rSMG) and left anterior superior temporal gyrus (laSTG). The interpretation of results from both modalities are highly compatible: The P300 has been identified as a locus of attention effects (Picton, 1992; Polich, 2007) especially for distinctive, emotional or 'oddball' stimuli (Briggs & Martin, 2009; Comerchero & Polich, 1998; Olofsson et al., 2008); and the rSMG has

also been noted as a locus for reflexive attention (which may be initiated by an emotional stimulus) as part of the ventral attention network (Corbetta, Patel, & Shulman, 2008; Corbetta & Shulman, 2002; Humphreys & Lambon Ralph, 2014). Indeed several studies have linked the source of the P300 component to the SMG (Horovitz, Skudlarski, & Gore, 2002; McCarthy, Luby, Gore, & Goldman-Rakic, 1997; Menon, Ford, Lim, Glover, & Pfefferbaum, 1997), providing strong evidence to suggest that the separate investigations of the current work may have identified a common 'source' of the EEM effect linked to attention. Likewise, the LPP component and STG brain region have both been associated with semantic processing and stimulus elaboration (*EEG*: Azizian & Polich, 2007; Codispoti, Ferrari, & Bradley, 2007; Weinberg & Hajcak, 2010; *fMRI*: Olson, McCoy, Klobusicky, & Ross, 2013; Visser & Lambon Ralph, 2011). However results of source localisation present an inconclusive description of the sources of the LPP (Liu, Huang, McGinnis-Deweese, Keil, & Ding, 2012; Scharmüller, Leutgeb, Schäfer, Köchel, & Schienle, 2011). For example, using concurrent fMRI-EEG data acquisition, Liu et al. (2012) found that LPP amplitude correlated significantly with the fMRI BOLD activity in a variety of brain structures, including the temporal poles (inclusive of the aSTG found in the current results) for negative emotional stimuli; although a source localisation experiment did not replicate this finding (Scharmüller et al., 2011). Amongst the supporting studies cited here there is a stark diversity in the methodology, statistical power, stimulus materials, and participant populations tested, and as such we exert caution in our assertion that the significant effects in both modalities may represent common sources.

When we probed the constituents of mixed list encoding more deeply with behavioural investigation (Chapter 6), we found that memory performance was

statistically equivalent when participants freely encoded the stimuli (the baseline comparison condition, representing encoding in the EEG and fMRI paradigms, and previous work) and when participants engaged in a relational processing task (designed to invoke semantic processing) at the expense of item-specific processing. Conversely, when participants engaged in item specific processing at the expense of relational processing, the EEM effect increased relative to the baseline group – a result driven by a decrease in neutral memory. Given that the relational task was designed to invoke a semantic relational decision, together these behavioural results once again highlight the importance of semantic processing, especially for neutral stimuli. Crucially, because we found that item-specific processing and relational processing were not equally as important for memory, we feel that there is not enough evidence to implicate a role for distinctiveness processing as defined by Hunt and McDaniel (1993) as a contributor to the EEM; and favour instead to refer to these results more generally as list-type effects.

7.3. Novel insights into the EEM effect: Mediation theory and beyond

7.3.1. Mediation theory

Importantly the neuroimaging data allow our interpretation to go beyond the current explanation of the EEM effect offered by mediation theory (Talmi, 2013). Although mediation theory cites attention as a cognitive factor of importance to the EEM; empirical data gathered in behavioural paradigms to date have been limited to examining the amount of attention – for example as measured by reaction times (RTs) to a prioritised tone task during emotional and neutral stimulus encoding. Findings of such studies are inconclusive: on the one hand demonstrating that

emotional stimuli do garner more attention than neutral (MacKay et al., 2004; Schmidt & Saari, 2007; Talmi, Schimmack, et al., 2007), and on the other hand suggesting that when emotional stimuli do receive more attention it does not always follow that memory is improved (Talmi, Schimmack, et al., 2007). Furthermore, even when attention is equated between emotional and neutral stimuli, memory for emotional stimuli is still better than that of neutral (Christianson et al., 1991; Mickley Steinmetz & Kensinger, 2013), suggesting that attention is not the sole mediator of the EEM effect.

The gathering of neuroimaging data has enabled the current experiments to go beyond the descriptions of the quantity of attention, and investigate instead the potential qualities of attention that contribute to the EEM effect (although we note that the quality or type of attention may also correlate with the amount of attention). Firstly, EEG data suggests that neutral stimuli in mixed lists suffer from a deficit of attention relative to other conditions, evident in an inverse Dm (forgotten > recalled) P300 effect. Although the P300 can be dissociated into the P3a and P3b sub-components which could potentially highlight a qualitative difference in attention between the conditions (P3a relates to reflexive attention), the overlap of the P300 and LPP effects in this data (sustained positive deflection >300ms) make this distinction difficult to identify.

However, the fMRI data extends our limited interpretation of the EEG data, by identifying the rSMG – known as part of the ventral attention network (VAN; referring to bottom-up, reflexive attention; Corbetta et al., 2008; Corbetta & Shulman, 2002) – as a significant contributor to the EEM in mixed lists. The rSMG was identified in a t-test comparing the neural correlates of successful mixed emotional encoding to those of successful pure emotional encoding (list-type x memory interaction), an effect that

was also a driving force of the three-way interaction results. In relation to this list-type x memory interaction result, identification of rSMG VAN activation suggests that reflexive reorienting happens to a greater extent in mixed lists compared to pure. This is a logical finding, given that a pure list allows for a (relatively more) uniform encoding strategy. However, it is notable that this greater activation in VAN areas does not correlate with a significant increase in emotional memory performance behaviourally; thus suggesting that this activation may reflect the requirement of a different kind of encoding strategy in mixed compared to pure lists, in order to maintain a consistent level of memory.

Whilst the neuroimaging results point to the three way interaction being driven by a significant mixed emotional Dm (mixed emotional Dm > pure emotional Dm, and > neutral Dm), behavioural results point to the interaction being driven by a reduction in mixed neutral memory (mixed neutral recall < pure emotional recall, and < mixed emotional recall). The answer of how to reconcile these seemingly discordant results lies partly in the behavioural results of chapter 6. As touched upon earlier, the results of this behavioural experiment suggested that the deficit of mixed neutral memory was caused (at least in part) by retroactive interference of emotional items on directly preceding neutral items. It is cogent then, to assume that these retroactive effects cannot be captured using event-related designs such as those used here to gather EEG and fMRI data. This is because at the time of stimulus presentation (when neuroimaging data is recorded) the encoding of a given neutral stimulus may appear to embody successful encoding; but it is not until the proceeding emotional item is presented that the detrimental effects on neutral item encoding are apparent (when neuroimaging data is no longer associated with neutral stimulus encoding). Therefore comparing neural encoding effects of neutral items presents little evidence to explain

the deficit in memory (mixed < pure), as the locus of this effect is actually outside of the encoding 'window' of neutral items, taking place at the time of an emotional stimulus onset. This proposal may go some way to explaining why the neural correlates of the main behavioural effect driving the three-way interaction (reduction in mixed compared to pure neutral memory) was so minimal (e.g. only identified in right PHC in fMRI results). Conversely, analysis of the fMRI data relating to greater mixed compared to pure emotional memory (which was not behaviourally significant), revealed relatively more neural correlates (identified most prominently in right hemisphere temporoparietal junction [TPJ] region activations: angular gyrus [AnG], supramarginal gyrus [SMG], frontal eye field [FEF], plus dorsal anterior cingulate cortex [dACC], dorsomedial prefrontal cortex [dmPFC], and left aSTG). Following this logic, we tentatively suggest that neural encoding effects identified for emotional stimuli, more likely reflect the mechanism by which the on-going encoding of neutral stimuli is disrupted. This assumption fits with the existing data; e.g. rSMG activity represents a sudden reflexive reorienting apparent for mixed emotional stimuli, which does not improve memory for that stimulus, but does – we suggest – impair memory for neutral stimuli as it detracts from necessary on-going processing.

In summary, the current data go beyond the quantification of attention as a mediator of the EEM effect as described by mediation theory; instead suggesting that the different encoding strategy for emotional items in mixed lists reflexively 'grabs' attention away from on-going neutral stimulus encoding resulting in poorer memory for neutral stimuli (but no increase in emotional memory).

Mediation theory also cites semantic relatedness as a cognitive factor of significance to the EEM; whereas the present neuroimaging data has afforded us the opportunity to go beyond this inference, more clearly dissociating semantic

relatedness as a property of the stimulus from semantic processing as a cognitive factor. The current results suggest that despite controlling semantic relatedness as a stimulus property (using SeRENS in which the within-set semantic relatedness of emotional and neutral stimuli was matched), differential semantic *processing* still contributed to the EEM effect. Convergent evidence to support this claim is apparent in the EEG, fMRI, and encoding manipulation behavioural data (chapters 4, 5, and 6). As detailed above, data from both EEG and fMRI modalities suggest the involvement of semantic processing (LPP component, and STG activity respectively), but the importance of semantic processing is perhaps most neatly apportioned in the behavioural data. The fact that relational processing did not improve memory relative to the baseline group suggests that this type of processing is naturally employed; and the fact that the effective elimination of item-specific processing in this group did not reduce memory suggests that this was not a contributory feature of the natural mechanism producing the EEM effect in mixed lists. Furthermore, when relational processing was effectively eliminated (in the ITEM group) this conveyed a significant detriment to neutral memory, inferring that neutral stimuli especially require this kind of processing.

The data suggest that the mechanism by which the encoding of neutral stimuli may suffer is through retroactive interference due to emotional stimuli. There is a wealth of supporting literature attesting to this kind of retroactive interference (Hurlemann et al., 2007; Strange, Kroes, Roiser, Tan, & Dolan, 2008; Strange, Hurlemann, & Dolan, 2003); however this literature has typically *described* the effects of retroactive interference, whereas the current experiments have begun to expand on this by providing a partial *explanation* of this effect, including factors that may be protective against retroactive interference. Analysis of the proportion of forgotten

neutral stimuli followed by emotional stimuli (E-1) in the ITEM group (where relational processing was eliminated) compared to the proportion E-1 in the baseline group confirmed that more retroactive interference occurred when less relational (semantic) processing resources were available. Bringing together this behavioural data with the neuroimaging data afford us an interpretation that is greater than the sum of its parts: EEG and fMRI data show that emotional stimuli invoke reflexive, bottom-up, attentional reorienting in mixed lists. When this reflexive reorienting mechanism is active and a relational task encourages semantic processing there is no extra detriment to neutral memory (neutral memory is less than emotional memory; but the difference in memory is comparable between RELATE and baseline conditions). However, when reflexive reorienting takes place and an item-specific task effectively eliminates semantic processing, this has a significantly detrimental effect on memory. Therefore this data shows that relational-semantic processing is generally more important than item-specific processing, and that semantic processing is of greater importance for the successful encoding of neutral stimuli compared to emotional stimuli (i.e. we propose as a protective mnemonic strategy against retroactive interference).

Furthermore, given that a lack of semantic processing was not also detrimental to emotional memory, we posit that an effect unique to emotional stimuli may also contribute to successful emotional memory. One plausible explanation is that the inherent motivational salience of emotional items (e.g. as indicated by increased physiological arousal; e.g. Bradley, Codispoti, Cuthbert, & Lang, 2001) is sufficient to drive emotional encoding in the absence of semantic processing. Although this finding would agree with the modulation model (McGaugh, 2004) – that arousal ultimately modulates emotional encoding – that is only part of the ‘story’ of

the immediate EEM effect; where the explanation of poor memory for neutral stimuli is just as important, if not more important, in explaining the mechanism of the immediate EEM. Once again these data go beyond the explanation of EEM offered by mediation theory which focuses on semantic relatedness instead of semantic processing. Moreover, we are the first to explain the role of semantic processing as part of a protective mechanism against retroactive interference in lists of mixed emotional and neutral stimuli.

Altogether this evidence presents an updated picture of the involvement of cognitive factors in the EEM. It appears that under mixed list conditions emotional encoding follows a different course to that of pure emotional encoding, which recruits bottom-up attention to maintain a consistent memory performance across both list types. Curiously, it would seem that the same mechanism which maintains memory performance for emotional stimuli may also be the mechanism which proves detrimental to neutral memory. For neutral stimuli, it would appear that an inherent lack of salience is further compounded by the mixed list conditions, which alter the mechanism of emotional encoding. This results in the effective prevention of successful encoding for neutral items which appears to be caused by retroactive interference of preceding emotional stimuli; an effect that worsens when semantic-relational processing resources are unavailable. Crucially, this places retroactive interference and semantic processing at the forefront of the mechanism explaining the mixed list EEM effect.

7.3.2. Binding theory

MacKay et al. (2004) suggest that emotional arousal instigates a mechanism which preferentially binds information of the stimulus to the context, resulting in better memory for such items. Perhaps most pertinent to the current body of work is Experiment 4 of MacKay et al. (2004) in which participants encoded taboo and neutral words presented in a rapid serial visual presentation (RSVP) task at a rate of 170ms/word during intentional encoding. Memory was tested with immediate free recall, and results showed that the memory performance for neutral stimuli presented before and after an emotional stimulus was significantly impaired. The authors interpret this by inferring that taboo words have an influence on their directly neighbouring stimuli (a local, not global effect within the list); that is to say that memory for neutral items presented amongst taboo items was not always impaired, only when a neutral item was temporally proximate to a taboo item. It is concluded that the preferential binding of the taboo item to the context of the list impairs memory of surrounding neutral items due to an interruption in the binding mechanism for neutral items for a limited duration of time. The current results presented in chapter 6 are compatible with this interpretation. Furthermore, the current results also go beyond this interpretation to provide more detail of the potential mechanism of item-context binding, and go some way to specifying the temporal properties of this mechanism. Indeed MacKay and colleagues themselves state that further evidence is required to determine the duration of preferential item-context binding effects.

As to the consistency of the current results with those of MacKay and colleagues – we also found significant retroactive interference, and can interpret this

as a local not global effect of emotion. This is evidenced by the fact that there was a significant difference in the memory performance of neutral items followed by fellow-neutral items (N-1), compared to neutral items followed by emotional items (E-1). If the effect of emotion was global this would have universally decreased memory for neutral stimuli in mixed lists, and the comparison of E-1 and N-1 incidences would have been non-significant. On the face of it, according to binding theory the fact that our slower presentation of stimuli (duration 2000ms, ISI 4000ms) still yielded the retroactive interference found in the RSVP paradigm gives the impression that item-context binding may take longer than 6 seconds. However, methodological differences between these paradigms could contribute to this impression, casting doubt on this interpretation. For example, MacKay et al. (2004) used words as stimuli, which may in themselves be quicker to encode than the complex (social) scenes of the current design (although see Van Doren, Schrooten, Adamczuk, Dupont, & Vandenberghe, 2012; in which reaction times to picture and word stimuli were comparable). Furthermore, taboo stimuli (as used by MacKay et al., 2004) have consistently been shown as a special category of emotional test materials (Buchanan et al., 2006; Hadley & MacKay, 2006; Kensinger & Corkin, 2003), and as such may be afforded a quicker binding mechanism compared to non-taboo emotional stimuli. Therefore, although the current results may not shed light on the duration of item-context binding in a taboo word RSVP task, we can assert that if differential item-context binding is to be deemed a suitable explanation of retroactive interference for complex scenes, then this process appears to take longer than 6 seconds. Put another way – if item-context binding took less than 6 seconds, then neutral item-context binding would have been completed before the onset of the following stimulus, therefore not affecting subsequent memory performance.

As described earlier (and in more detail in chapter 6) the present results suggest that a disruption of semantic processing is of particular importance to the impairment or success of neutral memory, however MacKay and colleagues did not venture to explain the psychological processes that could contribute to this neutral item-context binding deficit. One could conceive that the strong categorisation of neutral stimuli in the current design may well form an important part of the context of a given list, and therefore that semantic processing may be (part of) the psychological process that results in item-context binding. However, further research would be required in order to make this claim definitively.

7.3.3. ABC theory and GANE model

The work of Mather and colleagues led to the development of the ABC and GANE models (Arousal Biased Competition; Glutamate Amplifies Noradrenergic Effects; Mather, Clewett, Sakaki, & Harley, 2015; Mather & Sutherland, 2011; Sakaki, Fryer, & Mather, 2014); which explain the EEM effect by stating that arousal leads to the biasing of processing resources to prioritised information, leading to better memory via the creation of norepinephrine ‘hotspots’ in the brain. At first glance, this appears to fit well with the current data – pure lists represent no competition for resources and no differential-stimulus priority and therefore memory performance is equal for emotional and neutral stimuli; whereas in mixed lists differential arousal creates a competition for resources. Unfortunately, it is challenging to reflect on the implications of ABC theory (Mather & Sutherland, 2011) due to the circularity of the argument. Arousal is said to induce competition for resources, and resources are said to be allocated to stimuli of highest priority which leads to greater memory

performance; and yet greater memory performance is a central determinant of priority (in the absence of manipulating priority), and the difference in emotional versus neutral memory performance an indicator of competition for resources.

However, a recent update to ABC theory has provided better specificity of the mechanism assumed to take place, explaining how prioritised information receives more processing resources. This model (GANE; Mather et al., 2015) asserts that brain regions engaged in prioritised processing during a given task will maintain greater concentrations of glutamate, which – when a state of arousal is induced causing a relatively *global* rise in norepinephrine (NE) – perpetuates the production of yet greater *local* increases in NE which leads to ‘hotspots’ of neural activity resulting in better encoding and subsequent memory. This theory poses an answer to the question highlighted by Hamann (2001): how can arousal alone selectively enhance emotional memory, when the effect of arousal is long-acting, and remains present during neutral stimulus presentation? Despite the updated model’s specificity, it still remains to classify priority in a non-circular manner as described above. Based on better memory performance the current findings would suggest that emotional items have a higher priority at encoding; although this was not an instructed priority, and testing memory after manipulating item priority would be needed to confirm this. The inherent salience of emotional items may therefore pose a challenge for this model, as it may not be possible to sufficiently reduce emotional stimulus priority in favour of another stimulus category. Another challenge for this model is that because the model is based on neurochemistry, measures of BOLD obtainable with fMRI would not be specific enough to test this theory, and instead magnetic resonance spectroscopy and chemical exchange saturation transfer methods (Cai et al., 2013; Gigante et al., 2012) or positron emission tomography (PET) would be more suitable.

For example, recent research has made progress in identifying suitable PET ligands for the measurement of brain glutamate metabolism (e.g. imaging of the metabotropic glutamate receptor 1; Hong et al., 2015; Toyohara et al., 2013), and in the development of norepinephrine transporter ligands (Logan et al., 2005). However it may be some time before these methods are considered safe, economically viable, and ethical for application in human psychological experimentation.

All in all, the current findings can add to the discussion of the current understanding of the EEM effect. One note of importance is that many explanations of the EEM effect appear to refer to the EEM effect in isolation, and neglect to reflect on circumstances which might alter the EEM such as the way stimuli are organised (as pure lists of emotional *or* neutral stimuli; or mixed lists of emotional *and* neutral stimuli together). As the current findings demonstrate, there are significant differences in the mechanisms of pure and mixed lists, which – given the nature of many models of the EEM that consider only EEM in mixed list circumstances – can be of importance to these models as well as mediation theory. Moreover, there appears to be a relative neglect for describing and explaining detrimental effects on neutral memory, in favour of explaining the relative better memory of emotional items (possibly a hang-up from the tradition modulation model explanation). It is possible that there is a common explanation for both poor neutral memory performance and good emotional memory performance; however research should also consider that there may be two separable mechanisms at play causing the EEM effect (one supporting emotional memory, and one responsible for the detriment to neutral memory). Ultimately, if a greater understanding of the EEM effect is to be achieved, then the greater assimilation and testing of models will need to be a priority.

7.4. Implications for a unified model of the EEM effect

Generally speaking, the current findings present preliminary evidence detailing (some of) the cognitive psychological (and associated neural) effects that begin at encoding and correlate with an immediate EEM effect. Conversely, the modulation model (McGaugh, 2004) presents robust evidence of consolidation effects that begin at encoding and correlate with a delayed EEM (e.g. after many hours). To bring these models and others together (e.g. MacKay et al., 2004; Mather et al., 2015; Mather & Sutherland, 2011; van Kesteren et al., 2012) rigorous testing will be required, along with a determination to eliminate the use of ill-defined terms that are based on circular evidence (e.g. 'distinctiveness processing', and 'priority'). See Figure 7.1 for a proposal of a unified model of the EEM effect based on the current results.

At present, the current evidence can only attest to a short acting role for the effects of cognition on the EEM; however an adapted paradigm testing emotional and neutral memory at immediate *and* a delayed time interval would provide a basis for cognition as a contributor to the EEM per se. Based on the available data, the current findings suggest that different processes drive the EEM effect at different test latencies: A lack of cognitive resources may be integral to the relatively low neutral-stimulus memory in mixed lists, which drives the EEM effect at immediate test; whereas preferential consolidation over time is integral to the relatively high emotional stimulus memory, which drives the EEM at delayed test.

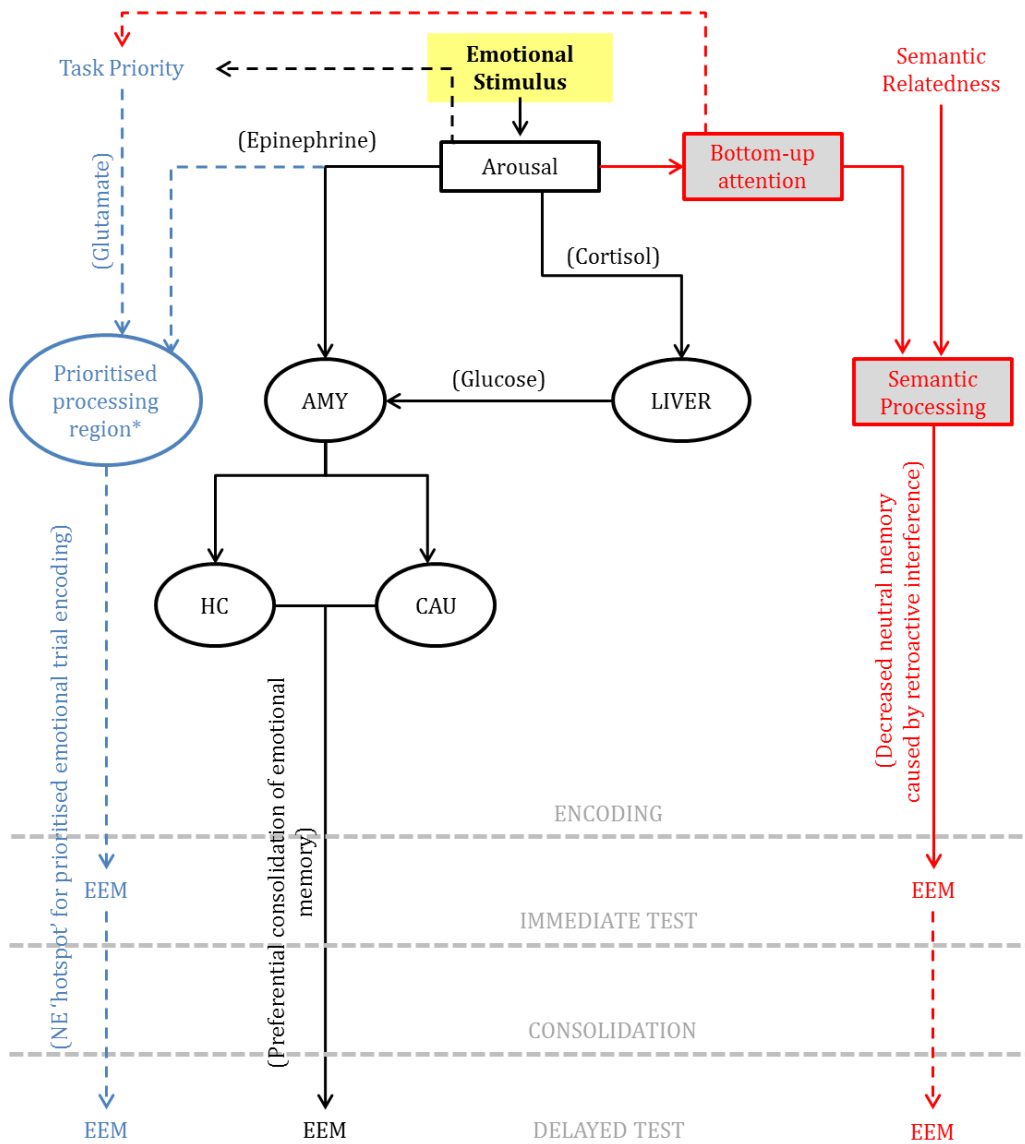


Figure 7.1. Diagram of preliminary unified model proposal explaining the EEM effect under mixed list circumstances

Simplified interpretation of the modulation model (black text, arrows etc.); and suggestions for parallel effects based on the current work (red text, arrows etc.), and the alternative GANE model. The EEM effects as explained by each model/data culminate in observable behavioural EEM (“EEM”) before consolidation (“IMMEDIATE TEST”) and after consolidation (“DELAYED TEST”), memory stages indicated by labels and grey dashed lines.

*Grey rectangles indicate cognitive processes; circles indicate anatomical regions; AMY = amygdala; CAU = caudate; HC = hippocampus; text in parenthesis indicates the mechanism of action from one point to the next; red dashed arrows indicate unknown / un-tested processes; blue dashed arrows indicate assumptions based on existing literature, but not currently explicitly tested; * indicates norepinephrine (NE) hotspot.*

7.5. Recommendations for future work

The current research represents an intermediate step in the journey towards a unified model of the EEM effect, by highlighting the importance of cognition to the EEM effect with behavioural and neuroimaging results. However, there are yet opportunities for further refinement of these results, and for future work investigating the EEM effect more holistically.

Extensions of the current work could be achieved quickly, and could add substantial value to the interpretation of these results. For example, for the EEG data, principle components analysis (PCA; Harner, 1990; Lagerlund, Sharbrough, & Busacker, 1997) may be useful to disentangle the P300 and LPP effects, which are thought to overlap from ~300ms onwards in the current data (consistent with Hajcak, MacNamara, & Olvet, 2010). This may allow for better specificity of the underlying cognitive psychological processes that contribute to the EEM effect based on the EEG data. Furthermore, source localisation (reverse modelling of EEG data accounting for certain anatomical and physiological assumptions to identify the source of brain activity) could be applied to the EEG data (for review see Michel et al., 2004), which would aid in the assessment of convergence between this data and that of the fMRI modality. Although one can draw on existing literature to link these two modalities (as discussed above), employing this tool would improve the certainty with which we interpret the current data. Although source localisation of electrophysiological signals from medial sources may not be well-specified (e.g. MTL in main effect of memory contrast; although see Attal & Schwartz, 2013), the fMRI data would suggest that results of the crucial three-way interaction analyses may be driven by sources in the neocortex, which should be more accurately localised.

Our interpretation of the immediate EEM effect based on the fMRI results could be improved by employing a functional connectivity analysis technique such as dynamic causal modelling (DCM; Friston, Harrison, & Penny, 2003). DCM allows researchers to investigate a discrete number of models to assess functional connectivity between specified brain regions. The models may specify input and output processes, brain regions, the direction of connections between regions (feedforward, feedback, reciprocal, inhibitory), and temporal order of connectivity. Given the identified regions of the fMRI results, and the temporal specificity of the EEG results, this would lend itself well to further probing with DCM. However, it should be noted that DCM cannot confirm that a given model truly explains behaviour, only that one model better explains the data compared to another.

Finally, the results of chapter 6 lend themselves to investigation via further empirical testing. For example, the current results suggest that retroactive interference acting on mixed list neutral stimuli, and the availability of semantic processing resources may be important factors; but the temporal limits and magnitude of these effects have not been specified. To this end, a further experiment could vary the inter-stimulus interval (ISI) and use this factor as a covariate in analysis to examine whether neutral memory performance has an inverse linear relationship to interference onset. In addition to this, analysis could also investigate pro-active interference, investigating whether emotional items also have a significantly detrimental effect on *proceeding* as well as *preceding* neutral items, consistent with MacKay et al. (2004) and emotional blindness literature (Kennedy & Most, 2012; Knight & Mather, 2009; Most, Chun, Widders, & Zald, 2005). A second experiment could address a further unanswered question: if less semantic processing led to greater interference and lower neutral memory performance, why was it that

encouraging semantic processing using the relational task did not improve neutral memory? The current interpretation proposed that the relational task allowed semantic processing to manifest at the same level as what is achievable in uninstructed 'free' encoding (baseline group); however a future study could selectively increase neutral stimulus semantic processing to see if this could reduce the magnitude of the mixed-list EEM effect. It may be possible to achieve this with extensive participant training regarding the process of the relational task, and / or priming with neutral-stimulus activities, and / or selectively targeting the neutral stimuli for semantic processing (i.e. participants are not asked to perform the relational task for emotional pictures). These proposed extensions would add considerable insights into the mechanism of the EEM effect and the contribution of retroactive interference of emotional items on preceding neutral items.

Crucially, to allow for a credible synthesis with existing models of the EEM effect (modulation model; McGaugh, 2004) the contribution of cognition will need to be tested at immediate and delayed tests. This will help to determine whether the EEM effect at immediate and delayed test is caused by two dissociable processes (cognition deficits impair immediate-test neutral memory; consolidation aids delayed-test emotional memory) or whether the cognitive effects identified here may endure, and therefore also correlate with a delayed EEM effect. Adapting the current paradigm to include immediate and delayed tests (e.g. combined with fMRI) is a formidable challenge for future research, as testing memory with free recall after a delay is somewhat impractical. The most straightforward suggestion would be for a single encoding list to be learned per day and tested the following day (leading to several scanning sessions over several days); however this may result in a greater likelihood of: participant drop-out, reduced signal to noise ratio, and non-economical

use of scanner resources. Free recall of all lists together would also not represent a viable option given that this would be much more taxing to memory, which we expect will result in low rates of recall, and given the greater difficulty in matching recall responses to a full set of stimuli rather than the 14 possible stimuli of each list used in immediate testing. Alternatively the argument may be made for using recognition memory testing rather than free recall, which would allow the testing of memory for many (and perhaps all) stimuli at once at a delayed test, however this presents its own difficulties. Free recall and recognition memory employ different mechanisms (Shiffrin, 2003), meaning that the current cognitive contributions to memory may not be so important when utilising a different test of memory. This was borne out by pilot data we collected (unpublished) using otherwise the same stimuli/paradigm as in the EEG and fMRI investigations, which did not replicate the robust patterns of EEM effects as found using free recall. With immediate recognition memory we found significant EEM effects in both mixed *and* pure lists, with greater memory and a larger EEM effect evident in pure lists. Because this method of testing memory may alter the status of memory for some items, the neural correlates of encoding based on this altered subsequent memory could not be expected to match those of the current research using free recall; and therefore such an experiment may be likely to produce false negative results. This discussion goes some way to eliminating infeasible plans to test emotional and neutral memory at two time points (immediate and delayed); however further thought and planning will be required to achieve a viable design. If such a viable paradigm could be designed and tested, a significant delayed EEM correlated with cognitive factors could go some way to identifying novel targets for psychological and pharmacological intervention in populations for whom negative

emotional memories are troublesome, e.g. in post-traumatic stress disorder, and major depressive disorder.

Moving beyond the current body of work and considering instead our understanding of the EEM effect more generally, an urgent task for future research will be to establish a clearer picture regarding how variations in methodology contribute to the extant divergent results. To this end a systematic review, or better – a quantitative meta-analysis (e.g. using the activation likelihood estimation [ALE]; e.g. Eickhoff et al., 2009; Laird et al., 2005) should be conducted, at least considering such parameters as stimulus type (e.g. aurally presented words, visually presented words, object pictures, complex scenes), test latency (immediate versus delayed test), and memory test type (free recall, cued recall, recognition memory). This would provide a much needed overview of the EEM effect per se, and would aid with the synthesis of a more holistic model of EEM.

In summary the current body of work has achieved its aims to develop a stimulus set which controls for between set semantic relatedness; to examine the use of the term distinctiveness processing to explain mixed list EEM effects; and to delineate the neural substrates of the mixed list EEM effect using EEG and fMRI. The current findings expand our existing understanding of the EEM effect; and have generated new, testable hypotheses that we hope will lead to future advances in the field.

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Appendix A

A.1. SeRENS Emotional original stimuli

IAPS #	filename	VC_ED	VC_FC	VC_SE	AVG arousal	AVG valence	AVG rel
6212	emotional010a	0.0865	4.876	3.269	5.96875	2.40625	5.034483
	emotional011a	0.0520	2.570	2.942	5.78125	2.5625	4.75
	emotional012a	0.0763	4.824	2.976	5.59375	3.09375	4.137931
	emotional013a	0.0448	4.994	3.020	6.6875	2	4.896552
3030	emotional014a	0.0773	4.357	3.046	5.75	2.96875	4.655172
	emotional015a	0.0748	5.267	2.927	7.09375	1.84375	5.448276
	emotional016a	0.0787	3.558	3.012	5.375	3.34375	4.413793
	emotional017a	0.0550	4.227	3.116	5.875	2.34375	5.241379
	emotional018a	0.0618	3.025	2.475	5.96875	2.78125	5.37931
	emotional019a	0.0865	4.387	3.366	6.5	2.65625	5.448276
9400	emotional01a	0.0850	6.956	3.229	6.375	2.40625	5.448276
	emotional020a	0.0885	3.678	3.083	5.34375	3	5
3170	emotional021a	0.0496	4.003	3.120	6.59375	2	4.655172
	emotional022a	0.0603	5.702	3.178	5.8125	2.5	5.068966
	emotional023a	0.0506	3.695	2.967	5.0625	2.9375	5.172414
	emotional024a	0.0260	4.445	3.049	5.9375	3.09375	4.62069
9433	emotional025a	0.1035	6.489	3.203	6.34375	2.34375	5.137931
9921	emotional026a	0.0799	2.993	3.202	6.125	2.625	4.413793
	emotional027a	0.1056	4.977	3.107	6.9375	1.78125	5.62069
	emotional028a	0.0375	4.620	3.490	5.59375	2.8125	4.586207
	emotional029a	0.1067	3.787	2.530	5.96875	2.875	4.793103
3266	emotional02a	0.0737	3.298	2.678	7.25	1.875	4.896552
	emotional030a	0.0793	3.235	3.081	5.3125	2.21875	4.862069
3120	emotional031a	0.0761	7.728	3.329	6.71875	2.1875	5.448276
	emotional032a	0.1276	4.448	3.061	5.78125	2.3125	5.586207
2800	emotional033a	0.0837	3.991	3.140	5.6875	2.625	5.034483
	emotional034a	0.0995	5.806	3.230	6.4375	2.71875	5.103448
	emotional035a	0.0920	5.089	3.216	6.90625	2.0625	5.413793
9253	emotional036a	0.0601	4.755	3.067	7.03125	2.0625	5.586207
9250	emotional037a	0.0685	3.967	3.031	5.53125	2.96875	5.62069
	emotional038a	0.0778	4.526	3.219	6.78125	2.1875	4.896552
3102	emotional039a	0.0417	5.926	3.237	7.03125	1.90625	5.517241
3550	emotional03a	0.0425	4.414	2.884	5.9375	2.78125	5.103448
	emotional040a	0.0624	6.356	3.459	5.96875	2.46875	5.413793
	emotional041a	0.0604	3.510	2.885	6.125	2.4375	5.551724
	emotional042a	0.0712	6.878	3.375	7	2.15625	5.275862
	emotional043a	0.0310	5.697	3.335	6.09375	2.71875	4.827586
	emotional044a	0.0759	3.072	3.004	6.5625	2.34375	4.896552

	emotional045a	0.0941	4.919	3.200	6.9375	1.9375	5.068966
9420	emotional046a	0.0716	2.631	2.843	6.875	2.21875	5.586207
	emotional047a	0.0517	4.848	3.142	5.125	3.125	4.034483
3500	emotional048a	0.0950	3.951	2.567	5.25	3.34375	4.482759
	emotional049a	0.0411	3.722	2.947	5.1875	3.0625	4.965517
	emotional04a	0.0818	5.689	3.146	6.1875	2.1875	5.551724
	emotional050a	0.0679	7.018	3.220	5.1875	3.1875	4.413793
2205	emotional051a	0.1086	5.051	3.325	5.125	2.90625	4.034483
	emotional052a	0.0837	7.681	3.360	5.34375	2.9375	4.793103
	emotional053a	0.0429	3.651	2.736	5.25	3.21875	5.034483
3110	emotional054a	0.0927	4.754	3.514	6.625	1.90625	5.206897
	emotional055a	0.0335	3.741	2.629	5.59375	2.34375	4.034483
	emotional056a	0.0626	4.467	3.333	5.4375	3.21875	4.862069
	emotional057a	0.1066	6.129	3.147	5.46875	2.71875	4.103448
	emotional058a	0.0588	3.229	2.934	6.28125	2.1875	5.241379
	emotional059a	0.0663	6.405	3.347	5.3125	2.8125	5.172414
	emotional05a	0.0693	6.967	3.121	6.03125	2.75	5.206897
	emotional060a	0.1258	4.274	2.993	5.15625	3.1875	5.068966
	emotional061a	0.0310	3.471	3.017	5.15625	3.25	4.103448
	emotional062a	0.1223	3.957	2.934	7.46875	1.75	5.068966
	emotional063a	0.1156	6.176	3.129	5.9375	2.6875	4.448276
	emotional064a	0.0586	4.305	2.824	4.96875	3.25	5.137931
	emotional065a	0.0385	5.660	3.214	6.3125	2.625	4.724138
	emotional066a	0.0569	5.731	3.001	5.90625	2.625	5.206897
	emotional067a	0.1070	5.811	3.068	5.875	2.71875	4.862069
	emotional068a	0.0989	6.417	3.214	7.28125	1.96875	5
	emotional069a	0.0858	3.863	3.180	6.21875	2.4375	4.655172
	emotional06a	0.0323	4.869	3.396	6.53125	2.0625	5.655172
	emotional070a	0.0910	3.537	3.208	5.09375	2.90625	4
	emotional071a	0.0815	4.065	2.874	5.09375	3.21875	4.310345
	emotional072a	0.0412	4.618	2.829	6.3125	2.09375	5.448276
	emotional073a	0.0710	5.400	3.115	5.0625	3.34375	4.655172
	emotional074a	0.0979	5.521	3.134	5.5625	2.875	5.206897
	emotional075a	0.0744	5.273	3.118	5.1875	2.96875	4.931034
	emotional076a	0.0802	4.408	3.284	6.3125	2.46875	5.931034
	emotional077a	0.1010	3.358	2.875	5.71875	2.625	5.172414
	emotional078a	0.0669	4.966	3.364	5.9375	2.21875	5.344828
3051	emotional079a	0.0997	5.050	2.745	6.34375	2.25	5.275862
6550	emotional07a	0.0541	3.888	3.014	6.4375	2.875	5.758621
	emotional080a	0.0743	4.445	2.876	5.21875	3.03125	4.310345
9042	emotional081a	0.0578	3.630	3.037	6.84375	2.5	4.034483
	emotional082a	0.0543	3.262	2.804	6.4375	2.375	4.310345
	emotional083a	0.0579	3.156	3.169	5.5625	2.84375	5.344828
	emotional084a	0.1193	3.195	3.150	5.71875	2.8125	4.724138
	emotional085a	0.0571	3.878	2.553	5.09375	3.1875	4.758621
	emotional086a	0.0528	3.756	2.887	5.15625	3.0625	5.37931

	emotional087a	0.0562	4.260	2.745	7	1.90625	4.482759
6315	emotional088a	0.0790	5.000	2.873	5.1875	3.03125	5.344828
3015	emotional08a	0.0966	6.440	3.318	7.40625	1.875	5.827586
	emotional09a	0.0640	3.334	2.836	5.4375	3.0625	4.586207

VC = visual complexity, ED = edge density, FC = feature congestion, SE = subband entropy, AVG = average, rel = relatedness.

A.2. SeRENS Neutral original stimuli

filename	VC_ED	VC_FC	VC_SE	AVG arousal	AVG valence	AVG relatedness
neutral0100a	0.0631	3.914	3.109	2.25	5.15625	5
neutral0101a	0.0551	3.144	3.040	2.25	4.9375	5.655172
neutral0102a	0.0592	4.028	2.924	2.03125	5.28125	5.733333
neutral0103a	0.1127	3.737	2.849	2.5	5.0625	5.466667
neutral0104a	0.0741	4.138	2.853	2.21875	5	5.2
neutral0105a	0.0375	4.643	3.008	2.375	5.25	5.766667
neutral0106a	0.0548	3.982	2.961	2.4375	5.5	5.466667
neutral010a	0.0390	3.507	3.086	2.03125	5.25	5.666667
neutral011a	0.0270	4.483	2.961	2.6875	5.6875	5.1
neutral012a	0.1085	5.405	3.221	2.4375	5.78125	4.8
neutral013a	0.0659	4.000	2.837	2.15625	5.71875	4.2
neutral014a	0.0480	5.917	3.307	2.4375	6.03125	4.666667
neutral015a	0.0893	7.004	3.130	2.53125	5.5	5.066667
neutral016a	0.0753	3.214	2.993	2.53125	5.375	4.965517
neutral017a	0.0855	6.770	3.133	2.6875	4.75	4.833333
neutral018a	0.0661	7.070	3.209	2.21875	5.375	5.633333
neutral019a	0.0672	4.297	2.944	2	5.0625	5
neutral01a	0.0515	2.796	2.955	2.5	6	5.066667
neutral020a	0.0506	4.658	2.956	2.3125	5.40625	5.166667
neutral021a	0.0734	4.949	2.948	2.21875	5.28125	5.433333
neutral022a	0.0473	5.444	3.137	2.125	5.40625	5.766667
neutral023a	0.0600	6.484	3.210	2.6875	5.6875	4.5
neutral024a	0.0499	3.551	3.196	2.34375	6	4.866667
neutral025a	0.0660	5.001	2.906	2.34375	4.90625	4.966667
neutral026a	0.0539	5.726	2.946	2.375	5.59375	5.3
neutral027a	0.0471	6.387	3.147	2.4375	5.59375	5.4
neutral028a	0.1022	4.335	2.915	2.21875	5.84375	4.566667
neutral029a	0.1044	6.174	3.284	2.6875	4.96875	5.366667
neutral02a	0.0810	3.962	2.971	2.0625	5.75	4.4
neutral030a	0.0366	5.067	2.916	2.65625	4.78125	4.433333
neutral031a	0.0799	5.879	3.200	2.0625	5.15625	5.466667
neutral032a	0.0576	4.190	3.058	2.375	5.3125	5.566667
neutral033a	0.0915	2.802	2.979	2.46875	4.96875	5.366667
neutral034a	0.0353	4.824	3.019	2.78125	5.5	5.3
neutral035a	0.0632	7.233	3.324	2.03125	5.46875	4.533333
neutral036a	0.0531	5.393	3.119	2.15625	5.125	5.433333
neutral037a	0.0633	5.402	2.876	2.625	5.84375	5.551724
neutral038a	0.0752	5.182	2.956	2.5	5.21875	4.1
neutral039a	0.0359	7.104	3.227	2.6875	5.4375	5.6
neutral03a	0.0567	5.438	3.122	2.6875	5.4375	4.866667
neutral040a	0.0431	6.069	3.065	2.0625	6.03125	4.5

neutral041a	0.0368	5.299	3.101	1.9375	5.0625	5.433333
neutral042a	0.0385	6.499	3.376	2.5	5.4375	4.566667
neutral043a	0.0488	4.940	2.983	2.5	5.125	4.9
neutral044a	0.0686	4.401	2.875	2.375	5.0625	5.6
neutral045a	0.0426	4.631	2.974	2.1875	5.75	4.933333
neutral046a	0.0828	4.805	2.980	2.1875	5.78125	4.7
neutral047a	0.0883	3.416	2.880	2.3125	5.5625	4.6
neutral048a	0.0846	4.557	3.147	2.15625	5.75	4.966667
neutral049a	0.0654	4.262	3.153	2.125	5.21875	4.233333
neutral04a	0.0612	4.802	3.095	2.34375	5.53125	4.466667
neutral050a	0.0854	4.420	3.020	2.5	4.90625	4.8
neutral051a	0.0461	4.651	2.840	2.65625	5.90625	4.033333
neutral052a	0.0943	6.834	3.040	2.4375	5.03125	4.8
neutral053a	0.0460	5.961	3.044	2.28125	5.625	5
neutral054a	0.0605	4.854	3.034	2.125	5.125	5.6
neutral055a	0.0905	6.012	3.126	2.5625	5.59375	4.4
neutral056a	0.0930	3.871	2.864	2.28125	5.8125	5.033333
neutral057a	0.0595	3.894	2.980	2.3125	5.3125	5.1
neutral058a	0.0567	3.453	2.976	2.46875	4.96875	4.233333
neutral059a	0.0913	3.815	2.930	2.09375	5.46875	5.433333
neutral05a	0.1019	7.028	3.316	2.40625	5.53125	5.033333
neutral060a	0.0426	6.560	3.306	2.28125	5.34375	4.4
neutral061a	0.0705	5.974	3.284	2.1875	5.28125	4.9
neutral062a	0.0793	4.476	3.091	2.21875	5.5625	5.066667
neutral063a	0.0620	5.347	2.950	2.40625	5.78125	4.9
neutral064a	0.0619	4.679	3.115	2.34375	5.0625	4.9
neutral065a	0.0658	5.541	3.175	2.1875	5.3125	5.3
neutral066a	0.0639	4.199	3.054	2.28125	5.5	4.366667
neutral067a	0.0644	3.897	2.897	2.1875	5.8125	5.366667
neutral068a	0.0772	3.709	3.062	2.15625	5.6875	5.133333
neutral069a	0.0703	5.211	3.333	2.125	5.34375	5.366667
neutral06a	0.0368	4.155	2.938	2.5	5.09375	5.5
neutral070a	0.0472	6.382	3.154	2.59375	5.53125	5.133333
neutral071a	0.0888	4.348	2.985	2.375	5.4375	4.4
neutral072a	0.0824	4.824	2.943	2.5625	5.53125	5.2
neutral073a	0.0479	4.511	2.923	2.3125	6.03125	4.6
neutral074a	0.0607	6.145	3.188	2.53125	5.71875	4.766667
neutral075a	0.0449	5.022	3.104	2.28125	5.46875	5.068966
neutral076a	0.0795	4.543	3.062	2.3125	5.28125	4.233333
neutral077a	0.0580	5.176	2.959	2.28125	5	4.333333
neutral078a	0.0832	4.277	3.009	2.75	5.9375	5.4
neutral079a	0.0850	6.339	3.264	2.3125	5.25	4.366667
neutral07a	0.0791	5.709	3.021	2.6875	5.0625	4.066667
neutral080a	0.0966	5.104	3.199	2.375	5.71875	4.633333
neutral081a	0.0909	6.012	3.161	2.5	5.4375	4.733333
neutral082a	0.0772	5.398	3.162	2.4375	5.625	4.833333

neutral083a	0.0703	4.651	3.034	2	5.6875	4.8
neutral084a	0.0633	4.879	3.009	2.375	5.9375	4.733333
neutral085a	0.0663	5.775	3.097	2.1875	5.6875	4.4
neutral086a	0.0457	3.914	3.007	2.25	5.0625	5.566667
neutral087a	0.0617	2.994	3.062	2.5625	5.875	4.966667
neutral088a	0.0907	5.808	3.190	2.25	5.03125	5.066667
neutral089a	0.0347	4.004	2.996	2.46875	5.28125	5.633333
neutral08a	0.0970	3.796	3.013	2.5	6.03125	4.433333
neutral090a	0.0468	3.792	3.077	2.40625	4.90625	4.6
neutral091a	0.0877	5.449	3.282	2.15625	5.15625	4.733333
neutral092a	0.0879	4.439	3.083	2.4375	5.71875	5
neutral093a	0.0904	5.713	3.222	2.25	5.28125	5.310345
neutral094a	0.0773	4.337	2.837	2.3125	4.875	5.566667
neutral095a	0.0599	5.833	3.039	2.03125	5.3125	5.733333
neutral096a	0.0749	4.475	3.101	2.1875	5.0625	5.733333
neutral097a	0.1113	7.017	3.122	2.625	5.15625	5.333333
neutral098a	0.0505	4.889	3.422	2.46875	5.71875	5.466667
neutral099a	0.0921	4.788	3.171	2.625	4.875	5.066667
neutral09a	0.0474	3.765	2.870	2.1875	5.09375	5.366667

VC = visual complexity, ED = edge density, FC = feature congestion, SE = subband entropy, AVG = average.

A.3. SeRENS Emotional duplicate stimuli

filename	VC_ED	VC_FC	VC_SE	AVG arousal	AVG valence	AVG relatedness
emotional010b	0.0662	2.432	2.666	5.15625	3.21875	4.551724
emotional011b	0.0761	5.050	3.204	5.75	2.78125	5.586207
emotional012b	0.0595	3.663	2.737	5.65625	3.46875	4.482759
emotional013b	0.0434	7.354	3.413	6.21875	2.28125	4.413793
emotional014b	0.0618	4.810	2.834	6.21875	2.5625	5.275862
emotional015b	0.0305	6.583	3.329	5.75	2.875	4.965517
emotional016b	0.0441	4.482	2.938	5.03125	2.96875	4.37931
emotional017b	0.0404	2.792	2.454	6.125	2.28125	4.586207
emotional018b	0.0582	5.593	3.333	6.5	2.375	5.586207
emotional019b	0.0962	2.850	2.809	5.84375	2.875	5.517241
emotional01b	0.0697	5.975	3.156	6.4375	2.21875	5.068966
emotional020b	0.0840	2.395	3.296	5.4375	3.03125	5.413793
emotional021b	0.0385	2.942	2.980	5.90625	2.375	4.413793
emotional022b	0.0576	3.253	2.876	6.75	2.125	5.206897
emotional023b	0.0466	6.015	2.989	5.4375	3.0625	5.068966
emotional024b	0.0785	5.514	2.998	5.71875	2.90625	4.103448
emotional025b	0.0597	3.159	2.889	6.75	2.375	5.172414
emotional026b	0.0612	6.569	3.323	5.90625	2.84375	4.034483
emotional027b	0.0350	4.793	2.978	6	2.34375	5.413793
emotional02b	0.0387	3.539	2.658	6.6875	2.4375	4.689655
emotional03b	0.0548	7.597	3.212	5.84375	3	5.172414
emotional04b	0.0529	4.733	3.146	6.1875	2.25	5.827586
emotional05b	0.1002	3.237	3.241	5.5	2.84375	5.344828
emotional06b	0.0366	5.129	3.108	5.5	2.6875	5.103448
emotional07b	0.0443	6.380	3.568	5.15625	3.1875	5.344828
emotional08b	0.0590	3.742	2.664	7	1.875	4.689655
emotional09b	0.1310	2.462	2.659	5.46875	3.25	4.103448

VC = visual complexity, ED = edge density, FC = feature congestion, SE = subband entropy, AVG = average.

A.4. SeRENS Neutral duplicate stimuli

filename	VC_ED	VC_FC	VC_SE	AVG arousal	AVG valence	AVG relatedness
neutral010b	0.0562	5.244	3.155	2.53125	4.84375	5.482759
neutral011b	0.0261	6.391	3.231	2.5625	5.0625	4.066667
neutral012b	0.0581	3.277	2.801	2.3125	5.8125	4.833333
neutral013b	0.0525	4.592	2.861	2.25	5.875	4.233333
neutral014b	0.0483	6.367	3.080	2.5	5.8125	5.033333
neutral015b	0.0707	5.042	3.282	2.1875	5.65625	5.3
neutral016b	0.0651	4.374	3.099	2.5	5.75	5.033333
neutral017b	0.1050	6.308	3.335	2.1875	5.25	5.066667
neutral018b	0.0906	2.925	2.973	2.125	5.53125	5.566667
neutral019b	0.0402	6.025	3.216	2.03125	5.25	5.137931
neutral01b	0.0496	4.003	2.730	2.34375	5.40625	5.266667
neutral020b	0.0634	5.415	2.928	2.59375	5.8125	4.933333
neutral021b	0.1015	4.061	2.678	2.3125	5.375	4.793103
neutral022b	0.0757	6.571	3.011	2.09375	5.21875	5.172414
neutral023b	0.0737	4.206	3.014	2.46875	6	4.6
neutral024b	0.0584	3.821	2.965	2.375	5.46875	5
neutral025b	0.0869	4.975	3.057	2.1875	5.4375	5.033333
neutral026b	0.0413	6.841	3.217	2.1875	5.125	5.166667
neutral027b	0.0373	5.198	2.981	2.21875	5.40625	5.433333
neutral028b	0.0620	3.355	2.935	2.1875	5.59375	4.9
neutral029b	0.0355	5.895	3.098	2.5625	4.84375	5.4
neutral02b	0.0805	3.725	2.686	2.4375	5.4375	4.166667
neutral030b	0.0612	4.561	3.097	2.5	5.03125	4.633333
neutral031b	0.0630	5.928	3.257	2.125	5.3125	4.933333
neutral032b	0.0706	3.789	2.593	2.1875	5.5625	5.3
neutral033b	0.0489	6.012	3.195	2.4375	4.96875	5.533333
neutral034b	0.0546	4.007	2.738	2.4375	5.53125	5.1
neutral035b	0.0755	5.075	3.125	2.15625	5.28125	4.633333
neutral036b	0.0476	3.885	2.813	2.46875	5.09375	5.344828
neutral037b	0.0646	6.038	3.103	2.15625	5.34375	5.433333
neutral038b	0.0782	4.517	2.835	2.71875	5.75	4.4
neutral039b	0.0583	5.610	2.964	2.5	5.5625	5.6
neutral03b	0.0342	5.418	3.170	2.125	4.96875	4.866667
neutral040b	0.0543	4.530	2.968	2.15625	5.40625	4.966667
neutral041b	0.0484	5.039	3.094	2.1875	5	5.166667
neutral042b	0.0610	3.557	2.859	2.28125	5.4375	4.413793
neutral043b	0.0427	6.202	3.116	2.3125	5.15625	5.766667
neutral044b	0.0474	4.049	2.816	2.25	5.125	4.866667
neutral045b	0.0448	3.875	2.984	2.46875	5.6875	5
neutral046b	0.0693	4.726	3.010	2.3125	5.875	5.1
neutral047b	0.0553	2.911	3.026	2.5	5.34375	4.866667

neutral048b	0.0794	3.823	2.781	2.1875	5.75	5.233333
neutral049b	0.0621	5.212	3.104	2.0625	5.46875	4.066667
neutral04b	0.0830	3.792	2.803	2.125	5.375	4.733333
neutral050b	0.0822	5.718	2.945	2.53125	4.9375	5.066667
neutral051b	0.0362	5.381	3.284	2.5625	5.65625	4.3
neutral052b	0.0466	5.202	3.143	2.375	5.71875	5.758621
neutral053b	0.0470	5.136	3.339	2.21875	5.21875	5.6
neutral054b	0.0793	5.763	3.176	2.21875	5.0625	5.7
neutral055b	0.0562	4.787	3.178	2.71875	5.90625	4.8
neutral056b	0.0396	4.917	2.943	2.59375	5.5625	5.4
neutral057b	0.0810	3.593	2.943	2.125	4.9375	5.366667
neutral058b	0.0464	3.230	2.651	2.53125	5.15625	4.4
neutral059b	0.0563	4.427	3.087	2.375	5.4375	5.033333
neutral05b	0.0759	4.514	3.124	2.71875	5.5	5.366667
neutral060b	0.0939	6.493	3.142	2.59375	5.9375	4.366667
neutral061b	0.0524	4.687	2.730	2.75	5.09375	4.966667
neutral062b	0.0747	5.788	2.829	2.4375	5.6875	4.9
neutral063b	0.0531	5.607	3.174	2.40625	5.75	4.9
neutral064b	0.0516	3.468	3.275	2.40625	4.9375	5.066667
neutral06b	0.0377	3.922	2.953	2.125	5.1875	5.133333
neutral07b	0.0720	3.825	2.775	2.53125	5.65625	4.333333
neutral08b	0.0878	3.581	3.093	2.5	6	4.033333
neutral09b	0.0444	3.813	2.995	2.40625	5.1875	5.266667

VC = visual complexity, ED = edge density, FC = feature congestion, SE = subband entropy, AVG = average.

Appendix B

B.1. Chapter 6 ANOVA results comparing proportion recalled scores between groups

In addition to testing our hypotheses using directly planned t-tests, we also employed an ANOVA approach. In order to investigate how each experimental group differed to the baseline group we began our analysis by conducting two separate 2 x 2 x 2 ANOVAs comparing ITEM to baseline and RELATE to baseline, using proportion recalled as the dependent variable; with list type (mixed, pure) and valence (emotional, neutral) as repeated measures variables, see Figure 6.2.

For the ANOVA comparing baseline and ITEM groups, we found a significant main effect of valence ($F(1,29) = 35.07, p < .001$), a significant valence x list type interaction ($F(1,29) = 23.65, p < .001$), and a significant valence x group interaction ($F(1,29) = 10.17, p = .003$). The three way interaction was not significant ($F(1, 29) = 0.67, p = .42$). For the ANOVA comparing baseline and RELATE groups, we found a significant main effect of valence ($F(1,32) = 10.48, p = .003$), a significant valence x list type interaction ($F(1,32) = 10.18, p = .003$), but the valence x group comparison was not significant ($F(1,32) = 0.17, p = .69$). The three way interaction was also not significant ($F(1, 32) = 0.23, p = .64$).

Given the graphs presented in Figure 6.2 we had a strong expectation that the three way interaction would be significant when comparing the baseline and ITEM groups; and therefore we conducted further exploratory analysis to investigate these data. We conducted two separate 2 x 2 ANOVAs with valence (emotional, neutral) as the within subjects variable and group (ITEM, baseline) as the between subjects variable, for mixed and pure lists separately. For mixed lists we found a significant

main effect of valence ($F(1,29) = 43.52, p < .001$) and a significant valence x group interaction ($F(1,29) = 5.97, p < .05$). For pure lists we found that the main effect of valence was not significant ($F(1,29) = 0.73, p = .40$), and the interaction between valence and group showed a non-significant trend ($F(1,29) = 4.13, p = 0.05$). In order to unpick the significant valence x group interaction for mixed lists, we conducted post-hoc independent samples t-tests (controlled for multiple comparisons using Tukey HSD) which compared proportion recalled mixed emotional for ITEM versus baseline; and the proportion recalled mixed neutral for ITEM versus baseline. For the emotional contrast we found that the between group difference was not significant ($t(29) = 0.51, p = .61, \text{Cohen's } d_s = 0.18$); whereas there was a significant between group difference for the neutral contrast ($t(29) = -2.83, p = .008, \text{Cohen's } d_s = -1.03$), which was also significant when controlled for multiple comparisons. We also tested these same contrasts for pure lists given that the p -value of the valence x group interaction approached significance. For the pure emotional contrast comparing ITEM and baseline we found no significant differences ($t(29) = 0.05, p = .96, \text{Cohen's } d_s = 0.02$); whereas the contrast for neutral data showed a non-significant trend ($t(29) = -1.97, p = .06; \text{Cohen's } d_s = -0.72$), and neither were significant when controlled for multiple comparisons.