Emotional words obtain priority in processing: Evidence from event-related brain potential and functional magnetic resonance imaging studies.

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„Überall geht ein frühes Ahnen dem späteren Wissen voraus.“

Alexander Freiherr von Humboldt (1769 – 1859)

„Es heißt: Ein Bild sagt mehr als tausend Worte, das mag stimmen, warum aber viele Worte in einem Bild ausdrücken, wenn man den passenden Begriff hat?“

Peter F. Keller (1949)

„Die stillen Worte sind es, die den Sturm bringen.“

Friedrich Nietzsche (1844 – 1900)

List of Abbreviations

Rating Scales and Questionnaires:

BDI	**Beck Depression Inventory**
SAM	**Self-Assessment Manikin**
STAI	**State Trait Anxiety Inventory**

Experimental Designs and Material:

ANEW	**Affective Norms of English Words**
IADS	**International Affective Sound System**
IAPS	**International Affective Picture System**
LDT	**Lexical Decision Task**
RSS	**Rapid Stream Stimulation**
RSVP	**Rapid Serial Visual Presentation**
SOA	**Stimulus Onset Asynchrony**

Brain Structures and Stereotactic coordinates:

BA	**Brodman Area**
MTL	**Mediotemporal Lobe**
MPFC	**Medial Prefrontal Cortex**
LPFC	**Lateral Prefrontal Cortex**
ROI	**Region of Interest**
MNI	**x, y, z Coordinates of Brain Structures according to Standard Brains from the Montreal Neurological Institute**

Neurophysiologic Methods:

EEG	**Electroencephalography**
EOG	**Electrooculogram**
EMG	**Electromyography**

ERP	**Event-Related Potential**
VEPs	**Visually Evoked Potentials**
N1	**N100 Potential**
P2	**P200 Potential**
EPN	**Early Posterior Negativity Potential**
RP	**Recognition Potential**
N2	**N200 Potential**
P3	**P300 Potential**
Startle probe P3	**P300 Potential of the acoustically elicited Startle Reflex**
N400	**N400 Potential**
LPP	**Late Positive Potential**
Fz, Cz, Pz, Oz, etc.	**Electrode Labels according to the International 10-20 System**
MNE	**Minimum Norm Estimate**
µV	**Microvolt**
fMRI	**Functional Magnetic Resonance Imaging**
PET	**Positron Emission Tomography**
BOLD	**Blood Oxygen Level Dependent**
hrf	**Hemodynamic Response Function**
rCBF	**Regional Cerebral Blood Flow**
EPI	**Echo Planar Imaging**
MPRAGE	**Magnetization-Prepared Rapidly-Acquired Gradient Echoes**
FOV	**Field of View**
T1	**'Spin-Lattice' Relaxation Time**
T2	**'Spin-Spin' Relaxation Time**
TA	**Acquisition Time**
TE	**Echo Time**
TR	**Repetition Time**

Neurophysiologic Software:

BESA	**Brain Electric Source Imaging**
SPM	**Statistical Parametric Mapping**
MRIcro	

Statistics:

ANOVA	**Analysis of Variance**
GLM	**General Linear Model**
$F(df_1,df_2)$	**F-value from ANOVA with degrees of freedom in parentheses**
T	**T-value from statistical T-Tests**
p	**Significance Threshold**
r	**Correlation Coefficient**
SDV	**Standard Deviation**

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Preface

In daily life, advertisement, literature and media demonstrate that words symbolizing attractive, desirable objects or objects of potential danger catch our attention, influence our thoughts and guide our behaviour. However, prioritized processing of emotional words has rarely been the focus of basic emotion research. The primary objective of this doctoral thesis was to fill this gap by investigating the physiological mechanisms underlying the selective processing of emotional words while healthy subjects spontaneously view or covertly evaluate highly arousing unpleasant and pleasant as well as low arousing neutral adjectives. Methodologically, high density electroencephalography (EEG) and functional neuroimaging techniques (fMRI) as well as peripheral, electromyographic measures of the defensive startle reflex were used to determine how, when and where in the brain emotional meaning affects information processing and emotional responses. Effects of emotional word processing on long-term memory were tested by surprise free recall tests in two of three experiments.

I. General Introduction

This chapter starts with a brief overwiew of traditional and contemporary views of emotion and language processing taking several constraints into account that we are confronted with when examining the processing of emotional words. Second focus is a detailed overview on the bio-informational theory of emotion (Lang, 1979), that constitutes the major theoretical framework of this doctoral thesis. Theoretical assumptions as well as related empirical research will be scrutinized with respect to the implications and hypotheses that can be drawn from them for the study of emotional words. The chapter ends with a basic description of the experiments under investigation.

1. Traditional and contemporary views of emotion and language

No phenomenon has fascinated human mind as much as emotion. From religion to philosophy, from medicine to psychiatry, emotion has been described as the boon and bane of human existence. The nature of what we call ‘the emotion’ has likewise been a subject of scientific interest. Many definitions from different fields of psychological research have been put forward to explain this complex but central phenomenon of our life.

Today, definitions of emotion concur in that the presence of an emotion includes at least the following aspects: (A) The occurrence of an emotionally significant external event, (b)

concomitant physiological changes in the body and the brain, (c) affective experiences such as feelings of arousal and pleasure or displeasure and (d) the generation of a contextually appropriate behaviour that is often, but not always, expressive, goal-directed, and adaptive (e.g., Kleinginna & Kleinginna, 1981; Phillips, Drevets, Rauch, & Lane, 2003). While emotions arise involuntarily when we are confronted with an emotional challenging stimulus feelings are often regarded as affective states that emerge from emotional processing as states of 'experienced', 'sensed' or 'recognized' emotions (e.g., Damasio, Grabowski, Bechara, Damasio, Ponto, et al., 2000; Frijda, 1986, 1999, 2004; Lang, 1995).

The extent to which a sensory stimulus is identified as emotive and influences our perception, experience and behaviour depends on its emotional significance. In natural environments important stimuli vary widely in form and function, raising the question how stimuli become emotionally significant and emotionally meaningful to an individual. As a product of evolution, emotions - unpleasant and pleasant - have been characterized as motivationally tuned states of 'vigilant readiness' preparing the organism to respond to events that motivate us to approach or avoid situations that protect our survival (e.g., Lang, Bradley, & Cuthbert, 1997a; Öhman, Flykt, & Esteves, 2001a; Öhman & Mineka, 2001b). In this view, many emotional stimuli obtained their survival relevance in the course of evolution (e.g., food- and noxious stimuli, snakes, spiders, or angry faces). Many other stimuli become emotionally reinforcing by means of different types of learning such as associative learning, emotional priming or by means of the significance an individual ascribes to this stimulus by both innate or highly overlearned knowledge acquired in the context of sociocultural and interpersonal situations (e.g., Adolphs, 2003a; Frijda, 1986; Lang et al., 1997a; Phelps, Connor, Gatenby, Gore, Grillon et al., 2001; Öhmann et al., 2001a, b).

There is no doubt that humans learn about emotionally aversive or rewarding properties of an environmental stimulus by direct experience with the stimulus. For instance, we develop a fear response by direct confrontation with a dangerous stimulus such as a snake and experiencing the snake's painful bite. However, we often learn about potentially dangerous or rewarding situations by means of language. It has been demonstrated that we can adopt a similar fear reaction to aversive stimuli not because we have made harmful experiences with these stimuli but someone has told us about it or we have read about it (Phelps et al., 2001). In humans symbolic representations of emotions conveyed by emotional words may be sufficient to enhance perception and preparation for action in a similar manner as has been demonstrated for direct confrontations with emotional stimuli or concrete pictorial representations of those stimuli (e.g., Lang, Greenwald, Bradley, & Hamm, 1993). On a neural level, the processing of emotional

words may be associated with similar responses of increased physiological arousal and augmented activation in brain structures that usually become activated when confronted with the emotional stimulus itself, such as the amygdala. However, these hypotheses have seldom been the focus of systematic emotion research. In contrast to the large body of literature that has focused on the neural basis of emotional face and emotional picture processing, comparatively little is know about the neural basis of emotional word processing. This may in part be due to historical reasons: Many traditional emotion and language theories imply a certain duality between emotions on the one hand and cognitive functions such as language on the other hand. In contrast to emotion, language has long been considered the most outstanding cognitive ability in the evolution of primates. Phylogenetically as well as ontogenetically language and emotion develop at different time points and both phenomena have traditionally been localized in different brain structures. Whereas emotional responses are assumed to be primarily controlled by ontogenetically old, subcortical brain structures, the classical discoveries of the French anatomist Paul Broca (1861) and the German researcher Karl Wernicke (1874), for instance, suggested that language production and comprehension are represented primarily in the left cortical hemisphere (Zuriff & Swinney, 1994). Of course, our understanding of emotion and language has become more complex today. Contemporary models of language as well as empirical research suggest that language processing and its representation in the brain incorporate both more elementary perceptual functions as well as higher-order cognitive operations (e.g., Friederici, 1995; Pulvermüller, 1996). Studies investigating the time course of word and picture processing have shown that meaning is extracted rapidly from words and even much faster than for concrete pictures (Potter, 1975; Potter & Kroll, 1987). Nevertheless, language and emotion research alike have payed little attention to the emotional aspects of word processing (e.g., Cacioppo & Gardner, 1999; Vandenberghe, Price, Wise, Josephs, & Frackowiak, 1996).

Based on his clinical observation that comprehension of affectively charged words is still intact in aphasic patients suffering from severe left-hemisphere damage, John Hughlings-Jackson (1835-1911) was one of the first researchers supposing an interaction between language and emotion in human brain development. Hughlings Jackson`s idea of a coevolution of language and emotion has been established in modern neuroscientific research only recently. Stressing the biological origin of emotion and language, metarepresentational theories of human information processing propose that language has become an important tool for expressing emotions. Besides communicative aspects, spoken and notably written language has facilitated the acquisition, the conveyance as well as the preservation of emotional meaning during the time course of evolution

and history (e.g., Damasio & Damasio, 1992; Reisenzein, 1998; Tucker, 2001). Although the objectivation of meaning may be a critical function of language, psychological studies have shown that besides its denotative aspects verbal semantic processing is generally based on emotional evaluations (Mehrabian & Russell, 1974; Osgood, Suci, & Tannenbaum, 1957). Using the 'semantic differential' technique, Osgood and collaborators (1975) have demonstrated that subjects of different cultures evaluate words according to their affective connotations. Factor analyses revealed three major evaluative dimensions. These dimensions constitute the fundamental emotion dimensions of influential contemporary emotion theories that will be described in detail below (e.g., Lang, 1979; Russel, 1980). The view, that the processing of symbolic stimuli such as words activates both semantic and emotional meaning representations has also been incorporated in semantic network models of emotion. These models assume that semantic and emotional meaning is stored in semantic networks that encompass information about the semantic, pragmatic and emotional connotations of a stimulus (e.g., Bower, 1981, Lang, 1979). The word 'snake', for example, elicits multiple semantic associations of the stimulus including knowledge about its emotional connotation and consequences. Although the last few decades have theoretically seen the seeds of change regarding our understanding of emotion and language, systematic empirical research is still sparse.

2. The bio-informational theory of emotion and its implications for emotional word processing

Peter Lang (1979) developed a bio-informational theory of emotion that has gained much attention in contemporary emotion research and appears most suitable for researchers interested in emotional word processing and its neural correlates. The theory incorporates and extends many of the theoretical assumptions derived from language research as well as from animal and human emotion research. The hypothesis that emotions can be characterized by principal emotional dimensions, as well as the idea, that emotional concepts are represented and stored in semantic networks, lie at the core of the bio-informational theory. As will be outlined in the following, the major advantage of the bio-informational model of emotion is that it integrates different aspects of emotion including motivational, physiological, behavioural and cognitive aspects. This allows a multi-dimensional analysis of emotional processing across different types of emotional stimuli and methods. Despite the fact, that many assumptions of the model have been based on language research, Lang himself intended to validate his model mainly for the processing of emotional picture stimuli (e.g., Lang et al., 1993; Lang, 1995). Since then, a multitude of emotion studies using Lang's standardized affective picture stimuli have been

conducted. Many of the results obtained from these studies will be presented below and in the following chapters. Using emotional words, the current thesis and its related experiments offer the possibility to validate the bio-informational theory for language stimuli and allow for a precise comparison of the emotional responses elicited by different types of non-verbal and verbal emotional stimuli.

2.1. The bi-motivational organization of emotion

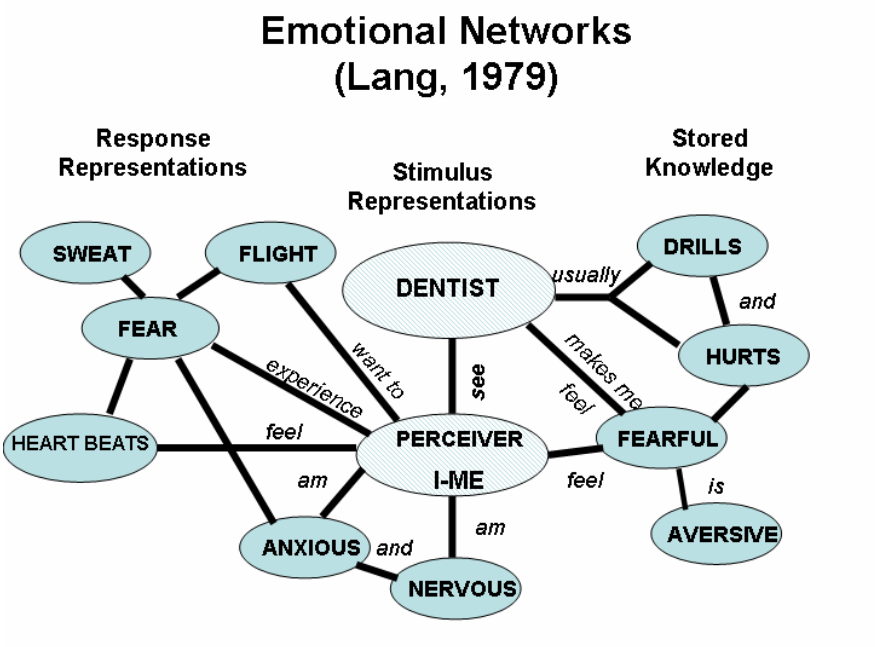
In contrast to categorical theories of emotion, that favour a set of distinct basic emotions (e.g., 'anger', 'fear', 'sadness', 'disgust', 'happiness' etc.), (e.g., Plutchik, 1962 for an overview), the bio-informational theory suggests that emotions are organized around two basic motivational brain systems, one appetitive and one defensive in nature. Although fear and anger, for instance, may be discriminable unpleasant affective states, strategically both emotional states emerge from activation of the same defensive system. Emotion – appetitive or aversive - emerges during direct confrontation with events, that either promote or threaten our survival. The defense system is primarily activated by stimuli requiring withdrawal, escape, and attack. Conversely, the appetitive system is activated by stimuli promoting procreation, copulation, ingestion and caregiving. Although overt behaviour, reported affect and physiology may vary according to situational demands and an individual's learning history, the response complexity is orchestrated by activation of either the approach system or the avoidance system (Lang, 1995). Thus, not the emotional responses themselves constitute emotions: Emotions are 'action dispositions' preparing organisms to be vigilant, aroused and responsive.

2.2. Emotional networks

The presence of an emotional stimulus primes emotional meaning representations, memory associations and action concepts. Together this information is stored in semantic networks and linked to the motivational brain systems (e.g., Lang, 1979, Lang et al., 1993). Emotional meaning is regarded to be stored in these semantic networks in an amodal, propositional format. The idea that emotional meaning elicited by different visual input modalities (e.g., pictures or words) converges on to the same set of meaning representations is consistent with cognitive neuroscientific accounts favouring a hierarchically structured, unitary system of semantic representations (e.g., Caramazza, 1996; Caramazza, Hillis, Rapp, & Romani, 1990, Rapp, Hillis, & Caramazza, 1993; Vandenberghe et al., 1996). Network models have a long tradition in

cognitive and language research (Pylyshin, 1981). In semantic network models information is regarded to be stored in interconnected 'nodes'. Accordingly, Lang (1979) assumes that emotional stimulus, emotional response and emotional meaning propositions are represented as 'nodes' that are jointly related via multiple associations (see Figure 1).

Figure 1: *Schematic overview of emotional networks sensu Lang, 1979.*



Moreover, physiological information about visceral and somatomotory affective states is stored in such networks, too. These 'nodes' and their associations are activated whenever subjects are confronted with emotionally significant external or internal stimulus events. For instance, when an individual sees a dentist or reads the word dentist (Figure 1), both percepts should elicit similar response and meaning associations, stored in the same emotional network in the brain.

2.3. Affective space of valence and arousal

When subjects are asked to judge stimuli according to their emotional meaning, multivariate studies of language processing have consistently revealed three superordinate factors, namely 'Evaluation' (good-bad), 'Power' (strong-weak) and 'Activity' (tense-relaxed), the first two factors accounting for the majority of the variance. Based on this seminal research on affective language processing and feelings (Mehrabian et al., 1997; Ortony, Clore, & Collins, 1988; Osgood et al., 1957; Shaver, Schwartz, Kirson, & O`Connor, 1987), Lang and colleagues

extended this body of research collecting ratings of different types of stimuli such as affective pictures, sounds and more recently also emotional words (Bradley & Lang, 1999a, b; Lang, Bradley, & Cuthbert, 1997b, 2005). The results consistently revealed three emotional evaluative dimensions of valence, arousal and dominance, with valence and arousal having the largest impact. These factors - notably valence and arousal - can be seen as reflecting the motivational activation of the postulated appetitive and defensive brain systems. The valence dimension indicates which of the two opposing motivational systems is active. Valence ranges from pleasure to displeasure and can be directed either toward (appetitive motivation, pleasant emotion) or away from (aversive motivation, unpleasant emotion) the stimulus. In contrast to valence, emotional arousal is unspecific and indicates the intensity of either appetitive or defensive motivational activation. Emotional arousal ranges from calm to exciting. The higher a stimulus is rated on the arousal dimension, the stronger the motivational engagement and the stronger the emotional responses elicited by this stimulus (e.g., Lang et al., 1997a).

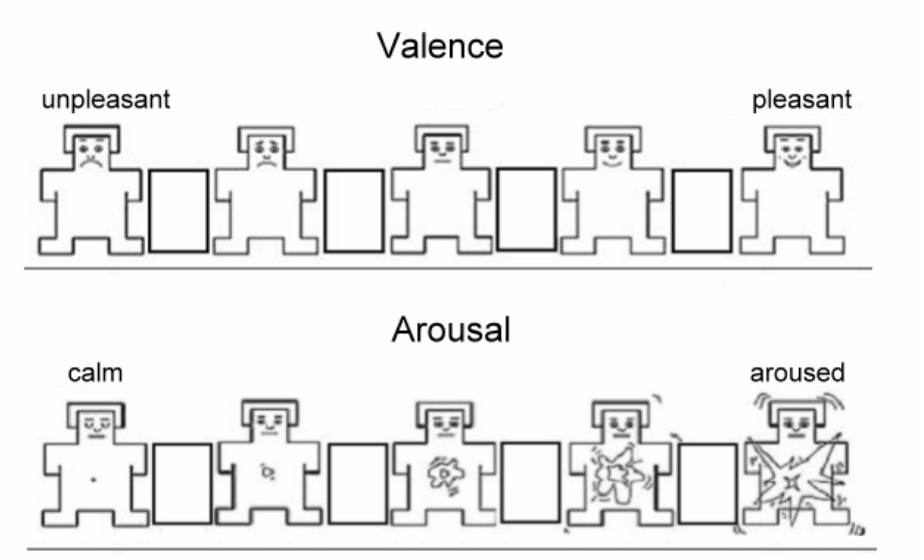
One premise of scientific research concerns the ability to obtain reliable and objective data. Therefore, an International Affective Picture Systems (IAPS) has been composed (Lang, et al., 1997b, 2005). The IAPS provides a set of normative emotional picture stimuli for experimental investigations of emotion and attention. It contains about 600 - 700 standardized, emotionally-evocative, colour photographs. The pictures include contents across a wide range of semantic categories mirroring many of the affects that occur in every day life (see Figure 3). For instance, unpleasant pictures show scenes depicting crime, attack, disgust, mutilated bodies or angry people and angry faces. Pleasant pictures show couples in love, erotica, sport events and happy faces and happy people. Neutral pictures depict household objects, natural scenes and neutral faces. Similar sets have been generated for acoustic and language stimuli such as the Affective Digitized Sound system (IADS) and the Affective Norms of English Words (ANEW) (Bradley et al., 1999a, b).

2.4. The Self-Assessment Manikin affective rating system (SAM)

To obtain standardized ratings on the three dimensions of pleasure, arousal, and dominance, Lang developed the Self-Assessment Manikin (SAM), an affective rating system (Lang, 1980). In contrast to culture-bound semantic differential techniques used in language research, the SAM provides a largely culture-free evaluative assessment of emotion. The SAM scales measuring valence and arousal correlate .9 with the major emotional dimensions ‘Evaluation’ and ‘Potency’ from the semantic differential techniques, predicting high construct validity (e.g., Bradley &

Lang, 1994; Hamm & Vaitl, 1993; Lang et al., 1997b). The SAM gives an easy to comprehend graphic representation of a nine-point scale of three emotional dimensions. The SAM scale that represents the valence dimension ranges from a frowning, unhappy figure to a smiling, happy figure. For the arousal dimension, the SAM scale ranges from a relaxed, sleepy figure to an excited, wide-eyed figure. The two major SAM affective rating scales of valence and arousal are shown in Figure 2. For the dominance dimension, SAM ranges from a large figure (in control) to a small figure (dominated). Each scale contains five figures that are separated by boxes. Subjects can select any of the 5 figures as well as the boxes resulting in a 9-point evaluative rating scale for each dimension. Ratings are scored such that the number 9 represents a high rating on each dimension (i.e., high pleasure, high arousal, high dominance), and the number 1 represents either high displeasure or low ratings of arousal and dominance (i.e., high displeasure, low arousal, low dominance). Since the dominance scale has been repeatedly found to account for relatively little unique variance it will not be described in further detail. The SAM can be applied as a paper-and-pencil version as well as a computer rating.

Figure 2: *The Self Assessment Manikin Scale. SAM scales are shown for emotional valence and arousal.*



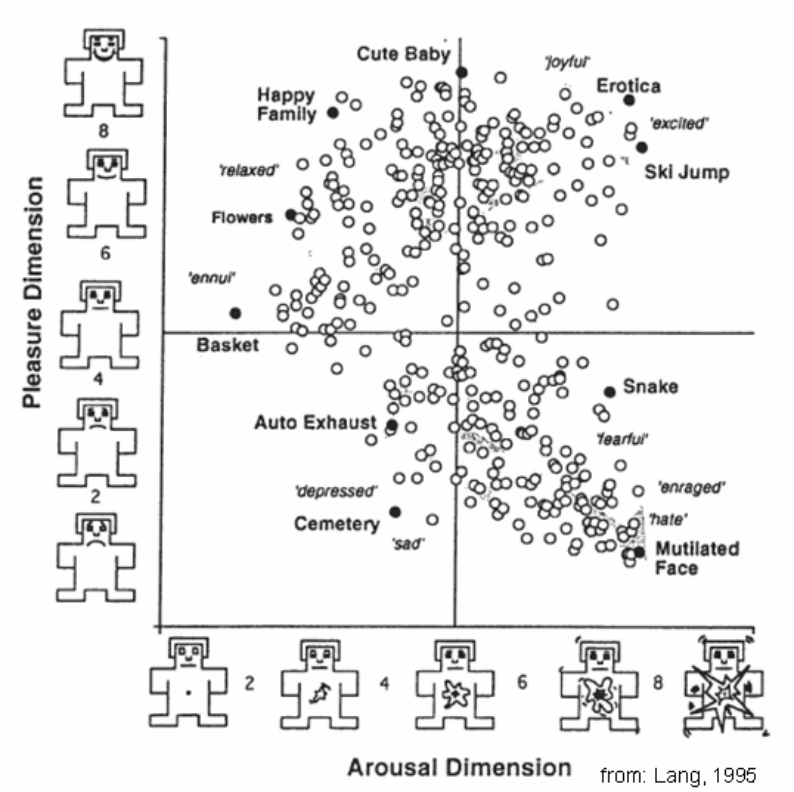
Normally, subjects are asked to rate their emotional feeling elicited by the presented pictures, sounds or words very spontaneously. The evaluation of each stimulus should reflect the immediate personal experience, and no more. SAM based evaluative judgements have shown good retest-reliability for both paper-and-pencil and computer administration. Using the SAM

instrument Lang has collected IAPS ratings of about 100 student subjects (e.g., Lang et al., 1997b; 2005).

2.5. Distribution of affective ratings in Affective Space

When each picture is plotted in terms of its normative mean SAM valence and arousal ratings a typical u-shaped distribution occurs. Figure 3 displays the distribution of a representative set of IAPS pictures, defined by normative valence and arousal ratings of student subjects. Results are plotted in a Cartesian two-dimensional affective space of valence (y-axis) and arousal (x-axis). As can be seen in Figure 3, unpleasant and pleasant stimuli evoke a bipolar distribution extending from neutral and calm toward pleasant and high-arousing or toward unpleasant and high-arousing dimensions.

Figure 3: *Distribution of a representative sample of IAPS pictures in affective space (from Lang, 1995). The labels represent the semantic category of the pictures.*



Regression analyses revealed a linear relationship between valence and arousal ratings. Pictures that are rated as either highly pleasant or highly unpleasant are also rated as more arousing (e.g., Hamm et al., 1993; Ito, Cacioppo, & Lang, 1998b; Lang et al., 1997b). Subjective judgements of

valence and arousal covary with activity in the autonomic and central nervous system validating the view of a neural basis of these two emotionally evaluative dimensions (e.g., Bradley & Lang, 2000; Lang, 1997a). For instance, unpleasant and pleasant pictures that are rated as highly arousing (e.g., pictures depicting threat, mutilation and erotica) elicit activation in a number of physiological systems. While heart rate and electromyographic activity of facial muscles is modulated differently by unpleasant and pleasant valence, skin conductance responses as well as cortical activation as measured by EEG increase linearly with changes in rated arousal.

2.6. Asymmetries in the processing of emotional stimuli

2.6.1. Individual differences

A growing body of studies demonstrate that emotional processing is biased in relation to individual differences in affect and physiological reactivity. While subjects with negative affect like depressive and anxious individuals respond more strongly to unpleasant than pleasant or neutral information, healthy subjects tend to prefer pleasant information (e.g., Ferré, 2003; Ito & Cacioppo, 2005; Lang, 1995; Lang, Bradley, & Cuthbert, 1998a; Taylor, 1991). Sex differences have also been reported, in that males are more likely to report high pleasure for arousing adventure and sexual stimuli whereas women tend to evaluate pictures dealing with threat and victimization as more unpleasant and arousing than males (Bradley et al., 2000). Evaluative ratings also vary across the life span: Older persons generally judge unpleasant stimuli as more arousing than pleasant ones, presumably because anxiety has been assumed to increase with age (e.g., see Bradley et al., 2000; Cuthbert, Lang, Strauss, Drobes, Patrick et al., 2003).
Together, the results point to a different excitability of the two motive systems of approach and avoidance in both sexes, across the life-span and in mood-disordered and healthy subjects.

2.6.2. 'Positivity offset' and 'negativity bias'

A stronger sensitivity and responsitivity of the approach or avoidance system may also be due to what has been termed a '*negativity bias'* and a *'positivity offset':* According to this view, both motivational systems are assumed to possess different operating characteristics: Whereas the motivation to avoid is stronger at high levels of emotional arousal ('*negativity bias'*) the motivation to approach is stronger at low levels of emotional arousal ('*positivity offset'*) (e.g., Cacioppo, 2004; Ito et al., 1998b, 2005). Laboratory experiments support these claims, showing that unpleasant IAPS pictures rated as extremely highly arousing evoke larger cortical responses

relative to pleasant and neutral IAPS pictures (Carretié, Mercado, Tapia, & Hinojosa, 2001; Ito, Larsen, Smith, & Cacioppo, 1998a). By contrast, larger processing effects for pleasant material than for unpleasant or neutral stimuli may benefit from lower arousal levels (Cacioppo, 2004; Ito et al., 2005).

A 'negativity bias' as well as a 'positivity offset' can also be inferred from the distribution of evaluative ratings of emotional stimuli in affective space. As can be seen in Figure 3, unpleasant pictures show a tendency to cluster at high levels of arousal indicating a 'negativity bias' (e.g., Cacioppo, Gardner, & Berntson, 1997; Ito et al., 1998b; Lang et al., 1997b). In contrast to unpleasant pictures, there are relatively more pleasant items located at lower levels of arousal indicating a stronger impact of pleasant valence than of unpleasant valence at lower levels of arousal. Although emotional evaluations may be biased in dependency of the stimulus` perceived emotional arousal intensity, motivationally appetitive and defensive engagement alike has been considered and also shown to require high levels of arousal (e.g., Lang, Bradley, & Cuthbert, 1992; Lang et al., 1993). Otherwise, motivational engagement will be less intense (cf. Lang et al., 1997b, pp. 2).

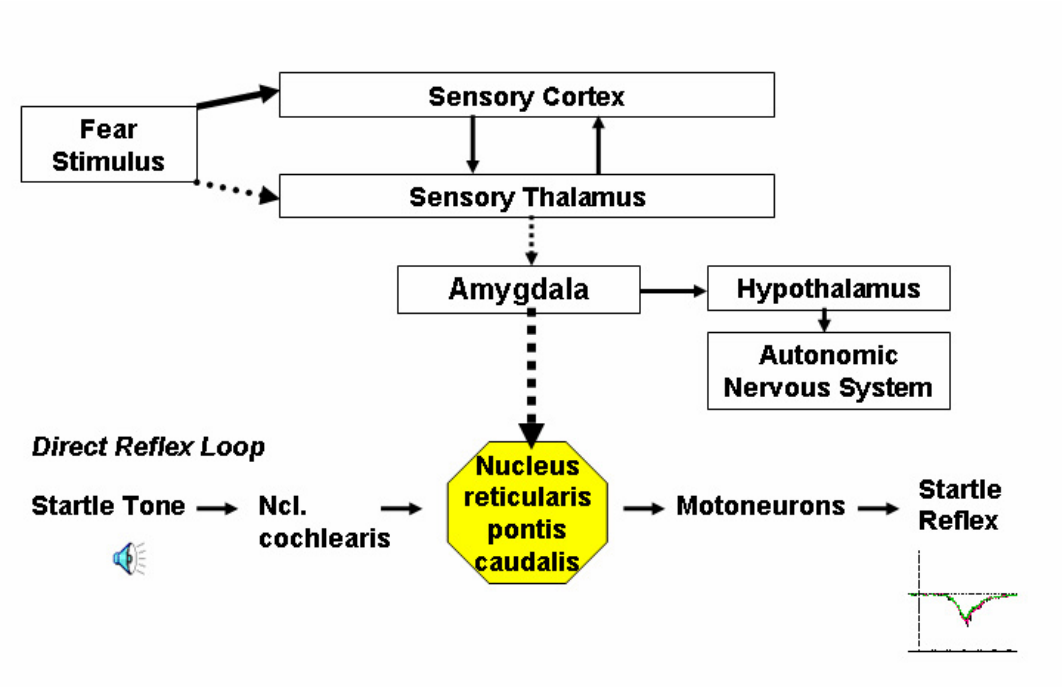
2.7. Motivational/emotional priming

Furthermore, it is assumed that both motive brain systems are activated reciprocally (Lang, 1995*)*: If activation in the defense system increases, activation of the approach system is inhibited and vice versa. Thus, in the context of an aversively motivated state, unpleasant stimulus associations and action programs should have a higher probability of access than those belonging to the non-engaged appetitive motivational system (e.g., Lang, 1994, 1995). This has been called motivational or emotional priming. Akin to the priming concept used in cognitive research (e.g., Anderson, 1986; Collins & Loftus, 1975) and consistent with the notion that emotional meaning propositions are stored in emotional networks, motivational priming is referred to as the process by which a prior exposure to an emotional stimulus makes emotional concepts and action programs more available as long as they are closely related to the same motivational subsystem. Motivational priming effects have been demonstrated repeatedly in affective picture studies probing affective modulation of defensive reflexes such as the startle reflex.

2.7.1. Affective modulation of the startle reflex

Reflexes can be either appetitive or defensive (Dickinson & Dearing, 1979; Konorski, 1967). Accordingly, defensive reflexes should be augmented when primed by unpleasant stimuli and inhibited by pleasant stimuli (e.g., Bradley et al., 2000; Lang, 1995). The startle reflex is one of the most prominent defensive reflexes elicited by any abrupt aversive sensory event. Typically, the startle reflex is associated with a series of rapid changes including motoric flexor movements of a variety of bodily muscles as well as changes in the central and autonomic nervous system (e.g., Berg & Balaban, 1999). One of the primary functions of the defensive startle reflex is to act as a 'behavioural interrupt' terminating ongoing cognitive processing and behaviour to deal adaptively with significant environmental change (e.g., Graham, 1979; Lang, 1995, Lang et al. 1997a). The neural circuitry of the startle reflex and its affective modulation is known from animal studies investigating fear-potentiated startle modulation (e.g., Davis, 1986). The schematic overview presented in Figure 4 shows, that the primary, hard-wired neural reflex pathway is influenced by a secondary, amygdala-driven pathway modulating aversive input.

Figure 4: *Neural circuitry of the defensive startle reflex (adapted from Lang, 1995).*

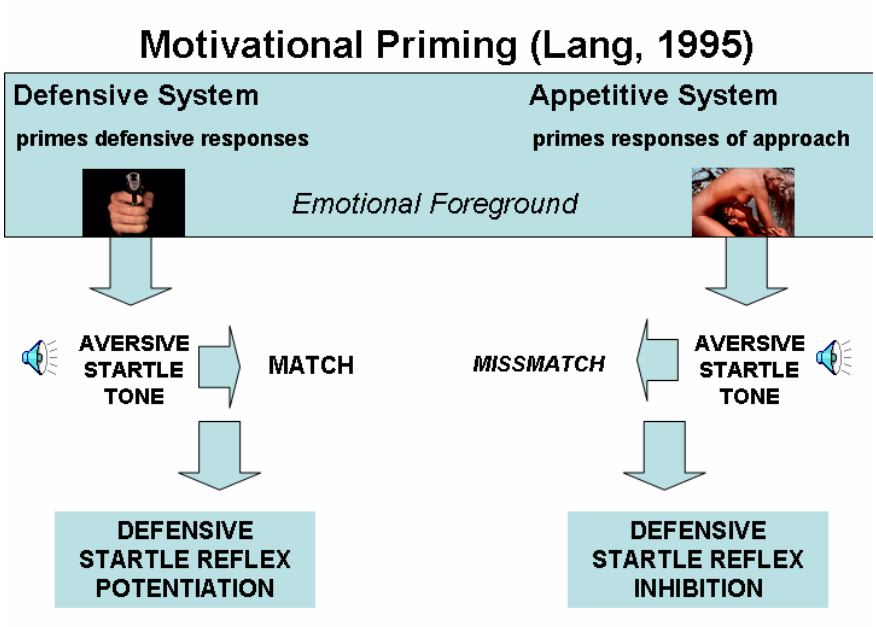


Aversive input is first projected to the thalamus and the sensory cortex. Both brain structures are directly connected to the amygdala. From the amygdala information is projected to the brain stem centres that modulate the startle response. The amygdala is heavily interconnected with a variety of neocortical and subcortical brain structures indicating that the startle reflex may be

variously shaped by additional input from other brain structures to the amygdala. Nevertheless, only lesions of the amygdala are capable of blocking fear-potentiated startle modulation (e.g., Davis, 1986 in Lang, 1995).

In humans the acoustically elicited startle eyeblink response has established a reliable marker of affective startle reflex modulation (e.g., Lang, 1995).[1] The startle eyeblink component reflects a sudden increase in tension in the facial muscle of the orbicularis oculi that can be measured, electromyographically beneath both eyes at about 30 - 50 ms after an intense startle tone has been presented (e.g., Berg et al., 1999). In support of the motivational priming hypothesis a series of affective picture viewing studies have shown that the startle eyeblink is potentiated during viewing unpleasant pictures and inhibited during viewing pleasant pictures indicating stronger response priming in conditions where defensive responses match with the valence of the stimulus (see for an overview Lang, 1995; Lang, Bradley, & Cuthbert, 1990; Lang et al., 1997a). A detailed description of these studies is presented in Chapter 4. Figure 5 and Figure 6 summarize the motivational priming hypothesis and respective empirical results, schematically.

Figure 5: *Motivational priming of the defensive startle reflex*

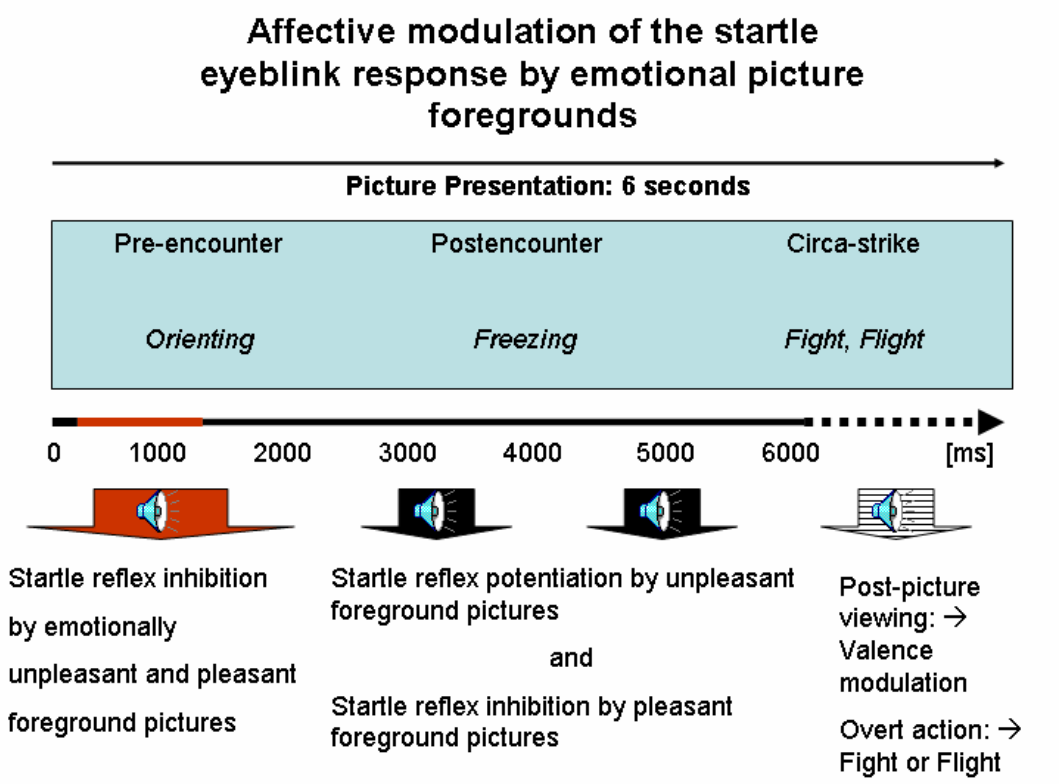


Valence modulation of the startle eyeblink seems to be most pronounced for emotional pictures rated as very highly arousing and for startle tones presented at about 1 - 2 seconds after picture

[1] Additional startle reflex measures such as the acoustically elicited startle 'probe' P3 potential have also been examined. The affective modulation of the startle 'probe' P3 potential will be explained and discussed in detail in Chapter 4.

onset (see for an overview Bradley, Codispoti, & Lang, 2006; Lang et al., 1997a). When startle tones are presented immediately (e.g., 50 ms) after picture presentation, blink responses are facilitated and not modulated by emotion. For startle tones presented shortly after a picture has been presented (e.g., 300 ms, 500 – 1000 ms), blink responses to unpleasant and pleasant pictures as opposed to neutral pictures are reduced in overall amplitude. Inhibited blink reflexes for both unpleasant and pleasant stimuli have been interpreted due to enhanced orienting responses to pleasant and unpleasant pictures which reduces sensory gating of simultaneously presented startle tones (e.g., Dawson, Schell, Swerdlow, & Fillion, 1997; Graham, 1979). Results obtained from empirical research using pictures as emotional foregrounds are summarized in Figure 6.

Figure 6: *Time course of affective startle modulation by emotional pictures*



The pattern of change from orienting to active defense and its consequences for affective startle modulation has been explained in terms of the defense-cascade model (e.g., Bradley et al., 2000; Lang et al., 1997a): During an initial phase of orienting termed 'pre-encounter' defensive and appetitive motivations may be activated simultaneously to allow for rapid orienting toward novel and emotionally relevant environmental stimuli. During orienting, response priming is less pronounced and defensive reflexes are inhibited. In a second phase called 'post-encounter',

orienting shifts to sustained or 'active' attention and preparation for action. In this stage, defensive responses are either primed by aversive sensory inputs to facilitate active defensive behaviour or inhibited by pleasant stimuli priming responses of approach. In a final stage, defensive reflex potentiation may give rise to overt behaviour of 'fight or flight'. The defense-cascade model predicts that motivational priming of defensive reflexes can be reliably assessed during a 'post-encounter' stimulus processing stage that is characterized by shifting a) from stimulus orienting to 'active attention' and b) from 'behavioural immobility' to the preparation of aversively or appetitively motivated action tendencies.

The startle eyeblink has also been investigated in post-picture viewing intervals and in conditions other than affective picture viewing such as during emotional imagery or emotional anticipation. While valence modulation has also been obtained in post-picture viewing intervals (e.g., Bradley, Cuthbert, & Lang, 1993; Cuthbert, Schupp, Bradley, McManis, & Lang, 1998), activation of both motive systems has been demonstrated to prompt blink potentiation during emotional imagery as well as during picture anticipation (e.g., Miller, Patrick, & Levenston, 2002; Sabatinelli, Bradley, & Lang, 2001; Witvliet & Vrana, 1995, 2000). Emotional anticipation and emotional imagery differ from picture perception and presumably also from post-picture viewing activity in several important ways. In contrast to picture viewing, emotional imagery, for instance, has been described as a 'cognitive-mentational' task accompanied by active sensory disengagement, directing attentional resources away from the sensory environment toward internal mental processing (e.g., Miller et al., 2002). In the context of enhanced internal engagement a simultaneously occurring startle eliciting tone may act as a 'cognitive' and 'behavioural interrupt' indicating successful reorientation to potentially harmful startle stimuli. Thus, it has been argued that the magnitude of the startle reflex increases in relation to the relative strength of mental engagement elicited by emotionally unpleasant and pleasant stimulus associations.

Concerning verbal material, only a few attempts have been made to examine startle blink modulation during emotional word processing. Many of those studies have focused solely on startle modulation by threatening in contrast to neutral words. The results are discussed in detail in the study described in chapter 4, that investigates startle blinks as well as startle 'probe' P3 potentials during viewing of emotionally highly arousing unpleasant, pleasant and low arousing neutral adjectives.

2.8. Emotion, Perception and Attention

Emotional stimulus processing influences a variety of cognitive functions such as perception and attention. When subjects passively view IAPS pictures in a free-viewing context, subjects spontaneously pay more attention to arousing unpleasant and pleasant picture contents than to neutral pictures as indicated by slower reaction time responses, longer viewing times and larger cortical slow wave potentials for highly arousing unpleasant and pleasant pictures than neutral and calm picture contents (e.g., Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 1996; Lang et al., 1997a for review). Thus, it has been posited that attention is primarily determined by motivation hypothesizing that stimuli capture and guide attention by means of their emotional/ motivational significance (e.g., Lang et al., 1997a). Motivated attention, that is, the emotional guidance of attention has been compared with a 'natural state of selective attention', similar to that occurring when we 'stop, look and listen, sifting through the environmental buzz for cues of danger, social meaning, and incentives to appetite' (cf. Lang et al., 1997a, pp. 98). From an evolutionary perspective the attention capture by emotional stimuli is assumed to be highly adaptive for survival. Motivated attention ensures rapid detection and discrimination of emotionally relevant stimuli from neutral ones for the purpose of responding rapidly with approach or defense and avoidance (Lang et al., 1997a). Of course, to be of true survival value emotionally challenging stimuli should capture and guide attention reflexively, regardless of whether these stimuli are 'to-be attended' or not.

2.8.1. Motivated attention and mechanisms of selective attention

The hypothesis of 'motivated attention' includes a variety of predictions that are critically related to general mechanisms of selective attention. Models of attention commonly assume that visual attention is limited in space as well as over time (e.g., Chun & Potter, 1995; Chun & Wolfe, 2001; Desimone & Duncan, 1995). Hence, stimuli have to compete for processing resources in order to become the focus of attention[2]. For this reason, only some stimuli may be consciously recognized and assigned to a more detailed and controlled stimulus evaluation (e.g., Chun et al., 1995). Attention models generally distinguish between different types of attentional control. A very common distinction is that between passive, stimulus-driven and active, goal-directed attention (e.g., Corbetta & Shulman, 2002; Öhman et al., 2001a; Yantis, 1998). Stimulus-driven selection concerns the more automatic type of attention found when an object, word or image not

[2] See for traditional attention models concerning early or late attentional selection accounts: Broadbent, 1958; Treisman, 1969; Deutsch & Deutsch, 1963; Norman, 1967.

related to the perceiver's goals and task instructions nevertheless draws his or her attention. Stimulus-driven attention is governed by bottom-up, perceptual processes and occurs rapidly in time at early levels of perception. In contrast to stimulus-driven attention, active or goal-directed attention has been characterized as top-down processing, initiated by task instructions or self-generated intentions. Thus, goal-driven stimulus selection concerns the more conscious type of attention.

The impact of motivated attention on perception and attention has been studied intensely in EEG-ERP studies and more recently also in neuroimaging studies investigating selective processing of emotional pictures and faces. A variety of different task settings have been applied to elucidate how priority processing of emotional stimuli is related to passive (stimulus-driven) and active (goal-directed) forms of attentional control and the availability of attentional processing resources.

2.8.2. Empirical research

A. EEG-ERP studies on motivated attention

Selective processing of emotional compared to neutral pictures is reflected by enhanced early and late ERP components. Cortical responses are generally assumed to covary positively with the amount of processing resources (e.g., Hopfinger, Luck, & Hillyard, 2004). The larger the amplitudes the more processing resources are engaged. Moreover, ERP components reflecting perceptual stimulus encoding, semantic processing, and stimulus updating in working memory are modulated by mechanism of selective attention (Eimer & Driver, 2001; Luck, Woodman, & Vogel, 2000; see Hopfinger et al., 2004 for an overview).

Concerning emotional stimuli, particularly two ERP components have shown robust and reliable affective modulation when IAPS pictures are presented briefly but clearly above the perceptual processing threshold.

A.1. Early and late selective processing of emotional stimuli

At early levels of perceptual processing, selective processing of unpleasant and pleasant IAPS pictures is associated with an increased early posterior negativity potential – termed EPN potential (e.g., Junghöfer, Bradley, Elbert, & Lang, 2001; Schupp, Junghöfer, Weike, & Hamm, 2003a; Schupp, Junghöfer, Weike, & Hamm, 2003b; Schupp, Junghöfer, Weike, & Hamm, 2004b). The EPN potential is characterized by a relative negative shift in the ERP waveform.

The EPN is most pronounced over temporo-occipital electrode sites at about 150 ms – 300 ms after picture onset. As often found for other peripheral indicators and late cortical potentials such as the LPP (e.g., Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Schupp, Cuthbert, Bradley, Hillman, Hamm, & Lang, 2004a), the EPN amplitude covaries systematically with the pictures` emotional arousal intensity and specific emotional picture contents. These contents presumably signal strong appetitive and defensive motives of high evolutionary significance (e.g., highly arousing pictures depicting erotica, sexual contents and contents of threat and mutilations) (e.g., Junghöfer et al., 2001; Schupp, et al., 2004b). Pictures depicting people and single objects have also been shown to elicit larger EPN amplitudes than complex scenic picture material (Löw, Lang, & Bradley, 2005). Affective modulation of the EPN component has been found in a variety of different task settings emphasizing the view that emotional pictures capture attention automatically, irrespective of whether the emotionality of the pictures is task-relevant or irrelevant: Affective modulation has been found although attentional capacities were limited due to rapid serial stream stimulation or due to the fact that attention was directed toward the processing of task-relevant non-emotional target stimuli (e.g., Junghöfer et al., 2001; Schupp et al., 2003b).

Despite the fact that early posterior negativity potentials such as the EPN component have proven reliable indicators of early selective processing of emotional pictures, direct evidence for similar modulation patterns elicited by emotional words is still lacking (see chapter 2).

Affective modulation of late event-related brain potentials such as the P3 potential and late positive potentials (LPP) belong to the most frequently reported findings observed in EEG-ERP emotion studies (e.g., Cuthbert, et al., 2000; Keil, Bradley, Hauk, Rockstroh, Elbert, et al., 2002; Schupp, Cuthbert, Bradley, Cacioppo, Ito, & Lang, 2000; Schupp et al., 2004a). The P3 and the LPP are assumed to reflect the representation of stimuli in working memory (e.g., Donchin & Coles, 1988) and conscious stimulus recognition (e.g., Luck et al., 2000). Findings of larger P3/LPP emotion effects for emotional stimuli than neutral stimuli thus imply a more detailed stimulus analysis, presumably due to a better representation of emotional than neutral stimuli in working memory. In agreement with this interpretation, larger late positive potentials to emotional than neutral stimuli covary with enhanced emotional memory performance (e.g., Dolcos & Cabeza, 2002; Palomba, Angrilli, & Mini, 1997). Affective modulation of P3 and LPP has been studied in a diversity of tasks. Generally, the results suggest that emotional stimuli also attract attention during later processing stages regardless of whether emotional stimuli are viewed passively (e.g., Keil et al., 2002) or attention is directed toward or away from the emotional stimulus. Emotional picture stimuli, for instance, have been associated with larger P3

potentials when used as deviant distracter stimuli in an oddball paradigm indicating enhanced reallocation of attentional resources to emotionally relevant cues (e.g., Delplanque, Lavoie, Hot, Silvert, & Sequeira, 2004; Delplanque, Silvert, Hot, & Sequeira, 2005).

As far as emotional IAPS pictures are concerned, ERP results support the hypothesis of motivated attention, showing that attention is captured automatically at early levels of stimulus perception (EPN) and is sustained during later processing stages (P3/LPP) by emotionally relevant stimuli.

Nevertheless, the extent to which emotional stimuli capture attention by default is debated controversially in the literature. On the on hand, behavioural, ERP as well as neuroimaging research suggests that emotional stimuli – especially those of high survival value – are detected and responded to even when presented outside the focus of perceptual awareness and without interference from processing of a secondary attention demanding task (e.g., Anderson & Phelps, 2001; Junghöfer et al., 2001; Liddell, Williams, Rathjen, Shevrin, & Gordon, 2004; Mack & Rock, 1998; Schupp et al., 2003b; Stormark, Hugdahl, & Posner, 1999; Öhman, Flykt, & Lundquist, 2000; Vuilleumier & Schwartz, 2001b). Based on converging evidence from behavioural, ERP and neuroimaging studies conducted by others and the author himself, Pessoa and colleagues (2005) however suggest that when processing of a primary, non-emotional task requires high attentional effort, emotional processing may be attenuated in most instances. In a recent ERP study, it has been found that affective modulation of the EPN potential to unpleasant and pleasant IAPS pictures decreased when processing load of a primary task was high (Schupp, Flaisch, Stockburger, & Junghöfer, 2006a). The data reveal that stimulus-driven selective processing of emotional stimuli as indexed by the EPN potential requires attentional resources. Thus, motivated attention may not always operate independently from attention processes devoted to concurrently presented, task-relevant stimuli. Moreover, recent EEG studies indicate that interference effects may also affect later processing stages indexed by the P3/LPP complex. Using facial stimuli, two studies reported modulation of early (120 ms post-stimulus) and late ERP components (300 – 500 ms post-stimulus) by facial expression (fearful greater neutral) when faces were presented at attended spatial locations. By contrast, differential responses of emotional and neutral faces were eliminated when faces were presented at unattended spatial locations (e.g., Eimer, Holmes, McGlone, 2003; Holmes, Vuilleumier, & Eimer, 2003).

The ERP study described in chapter 2 will provide insight in how emotional words guide attention at different processing stages in the context of passive viewing conditions and limited

capacities to attend to briefly and repeatedly presented streams of words. Additional data will be reviewed concerning findings obtained from language, cognitive and emotion research.

B. Neuroimaging studies on emotional perception and motivated attention

It is of note here, to mention that at the time the bio-informational theory was developed many of the assumptions concerning the organization of motivational brain systems was based primarily on animal models stressing the relevance of the amygdala in fear processing (e.g., Lang, 1979, 1995). Since then, increasing evidence from human research has shown that the amygdala is not specialized for the processing of fear but responds to emotionally relevant information of either unpleasant or pleasant emotion (see Sander, Grafman, & Zalla, 2003; Zald, 2003 for reviews). Besides fear processing, the amygdala likely serves a more general function of alerting the organism toward emotionally salient stimuli by guiding sensory processing once these stimuli have been identified as emotionally meaningful.

Because of the importance of the amygdala in emotion processing in general and in selective processing of emotional stimuli in particular some basic information concerning the amygdala and the major pathways along which the amygdala is thought to modulate the perception of emotional stimuli will now be described in more detail.

B.1. The amygdala

The amygdala *(corpus amygdaloideum)* is an almond-shaped brain structure located in the brain`s left and right mediotemporal lobes (Adolphs, 2003b). Together with the hypothalamus, the parahippocampal system including the hippocampus and brain structures in the frontal cortex (e.g., parts of the anterior cingulate gyrus, the medial prefrontal and orbito-frontal cortex) it is part of the limbic system. Each amygdala consists of a collection of thirteen brain nuclei that have been grouped together into three clusters according to their functionality (e.g., basolateral complex, the centromedial nucleus, and the cortical nucleus). Here, and in the following chapters I will refer to the amygdala complex as a whole (see LeDoux, 2001 for a detailed overview).

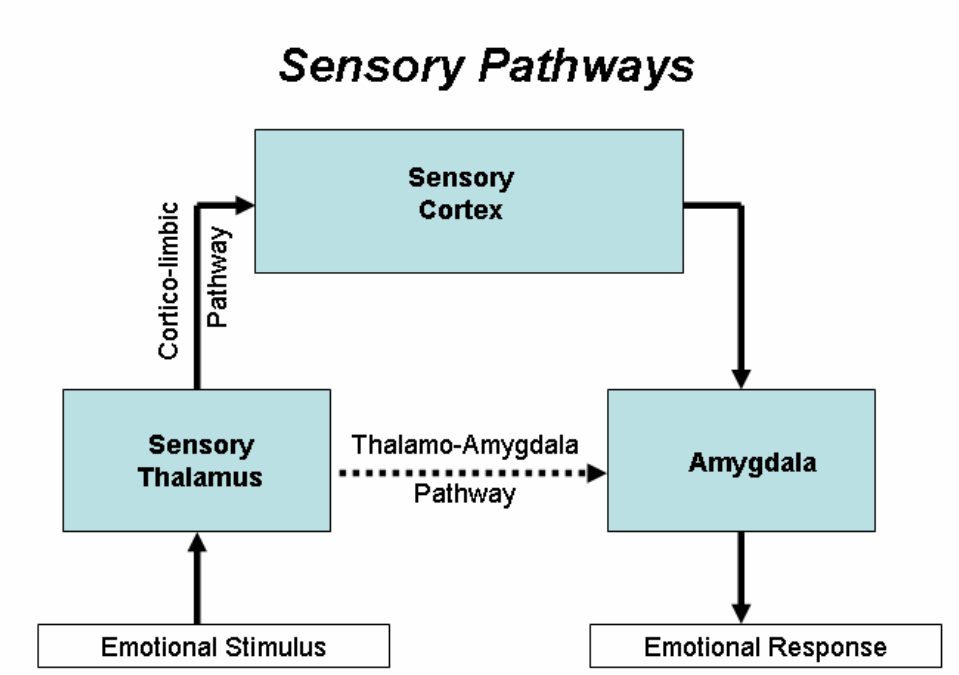
The amygdala provides links to, receives output from and projects information back to several cortical and subcortical brain structures that play a crucial role in perception, attention, memory, and the modulation of visceral and autonomic responses. Much of this input subsequently leaves the amygdala through amygdalafugal pathways to re-enter many of the same areas that send efferents to the amygdala. The amygdala also projects to the brain’s arousal system including the

cholinergic brain stem arousal system and the basal forebrain cholinergic arousal system. Neurons of the arousal system innervate widespread areas of the cortex (e.g., Aston-Jones, Rajkowski, Kubiak, Valentino, & Shipley, 1996; Gallagher & Holland, 1994; Kapp, Whalen, Supple, & Pascoe, 1992). Arousal plays a critical role in nearly all kinds of information processing. Thus, once the amygdala is activated by an emotional input it may enhance sensory processing indirectly by activating arousal systems (LeDoux, 2001). Although arousal has been regarded as unspecific activation of the basal forebrain arousal system facilitates neuronal responsivity of those cortical areas that are already activated (Kapp et al., 1992; LeDoux, 2001).

B.2. Sensory amygdala pathways

As far as sensory input is concerned, the amygdala responds to visual, auditory, somatosensory, and all types of visceral input. Most of the information from the exteroceptive sense organs reaches the amygdala via two major sensory pathways (see Figure 7).

Figure 7: *Sensory pathways involved in unconscious and conscious perception of emotional stimuli (adapted from LeDoux, 2001).*

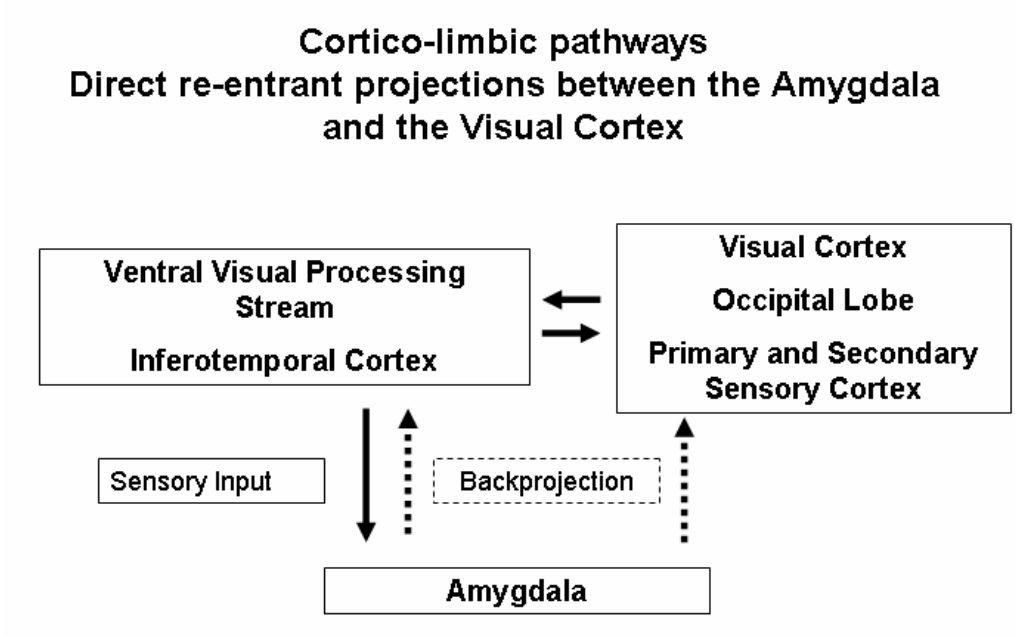


From the thalamus the amygdala receives rapid and crudely processed exteroceptive information. Therefore, evaluation of sensory input occurs on the basis of simpler stimulus features and presumably without conscious awareness (LeDoux, 2000a, 2001). A large body of empirical

work has underscored the role of the thalamo-amygdala pathway in fear conditioning as well as in the facilitated detection of fear eliciting stimuli although stimuli were presented below the threshold of conscious stimulus detection (e.g., Liddell, Brown, Kemp, Barton, Das et al., 2005; Morris, deGelder, Weiskrantz, & Dolan, 2001; Morris, Öhmann, & Dolan, 1999; Pasley, Mayes, & Schultz, 2004). The thalamo-amygdala pathway has limited sensory coding capacities. By means of thalamic input the amygdala cannot discriminate between a threatening snake and an innocuous stick. To accurately discriminate emotional stimuli from neutral ones the amygdala requires further input from the sensory cortex (e.g., Öhmann et al., 2001a; Rolls, 1999; Rolls, Tovee, & Panzeri, 1999). Empirical evidence for a primarily subcortical processing pathway has so far been validated for specific types of fearful stimuli that have obtained their emotional significance on the basis of fear conditioning or during the course of evolution such as fearful faces or pictures of snakes and spiders. For several other types of stimuli such as emotionally arousing pictures or words, facilitated detection of emotional stimuli appears to be not entirely subcortical but relies on further stimulus encoding in cortical brain regions such as the visual cortex with which the amygdala is heavily connected (e.g., Keightley, Winocur, Graham, Mayberg, Hevenor et al., 2003; Naccache, Gaillard, Adam, Hasboun, Clemenceau et al., 2005).

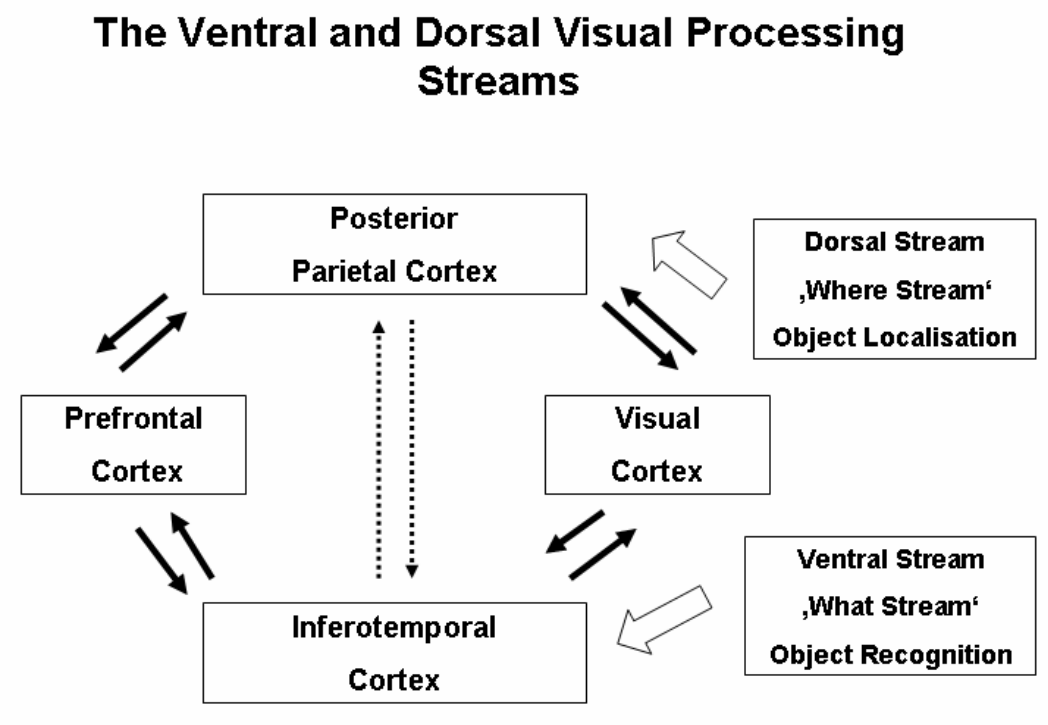
The amygdala receives sensory information from 'higher-order' areas of the ventral visual processing stream. In contrast to the direct thalamo-amygdala pathway, this sensory input reaches the amygdala in a highly processed manner. The amygdala also projects back to those visual areas as well as to the primary and secondary visual cortex areas comprising all levels of the ventral visual processing pathway (see Figure 8). Thus, the amygdala shares reciprocal feedback projections with 'higher-order' visual areas and sends afferent non-reciprocal projections to earlier stages of visual processing (Amaral, Price, Pitkaenen, & Carmichel, 1992; LeDoux, 2001). The output of the amygdala also reaches polymodal association areas located in adjacent brain regions of the mediotemporal lobe memory system (e.g., anterior parahippocampus, hippocampus) and prefrontal and orbito-frontal cortex. These brain areas are responsible for the integration of emotional information with other types of sensory, cognitive and memory information, amongst others (e.g., Barbas, 2000; Pandya & Yeterian, 1985).

Figure 8: *Cortico-limbic pathways involved in visual perception of emotional stimuli (adapted from Amaral et al., 1992).*



When a visual stimulus enters the visual cortex information is processed differently along two major visual pathways each originating from the primary visual areas (e.g., Ungerleider & Haxby, 1994; Ungerleider & Mishkin, 1982). These two major visual processing streams are shown in Figure 9. Visual input to the ventral visual stream is projected from the primary visual areas to the inferior temporal cortex and to inferior frontal cortex structures. Because the ventral visual stream plays a critical role in object recognition it has been termed the 'what' stream of visual processing. Visual input to the dorsal visual stream is projected to the posterior parietal cortex and superior prefrontal cortex regions. The dorsal visual stream is concerned with 'control of behaviour' (e.g., Miller & Goodale, 1993) and modulates the localization of and movements to these objects. It has been termed the 'where' stream of visual processing. Neuroimaging studies investigating visual attention suggest that stimulus-driven and goal-driven attention, are controlled by distinct but interacting brain systems: During normal vision, goal-directed (top-down) stimulus selection enhances activity in the dorsal visual processing stream including brain areas of the intra-parietal cortex and superior frontal cortex. Stimulus-driven (bottom-up) selection enhances activity in the ventral visual processing stream including brain areas in the inferior frontal cortex and ventral visual cortex. Activation here increases during the detection of behaviourally relevant stimuli, particularly when they are salient or unexpected (cf. Corbetta et al., 2002, p. 201).

Figure 9: *The ventral and dorsal visual processing stream modulation of object recognition and object location (adapted from Ungerleider et al., 1982, 1994 and Pessoa, Kastner, & Ungerleider, 2002a).*



Despite the fact that visual information is processed along different ventral and dorsal visual processing pathways much of the information concerning the 'what' and 'where' is processed in parallel (Ungerleider et al., 1982). Moreover, tracing studies in primates (e.g., Webster, Bachevelier, & Ungerleider, 1994) have revealed direct connections between both visual processing streams including areas in the infero-temporal and parietal lobes (see Figure 9 dotted arrows).

To date, a convincing set of neuroimaging studies suggests that the amygdala facilitates perceptional processing of emotional stimuli by its direct projections to regions of the ventral visual processing stream. Evidence has been derived from functional imaging (fMRI) and positron emission tomography (PET) studies. FMRI and PET studies report enhanced activation in the amygdala and the extrastriate visual cortex (e.g., fusiform gyrus and extended inferior temporal areas) during the processing of fearful and/or happy faces in contrast to neutral faces as well as during the processing of highly arousing unpleasant and/or pleasant IAPS pictures in contrast to neutral IAPS pictures (e.g., Breiter, Etkoff, Whalen, Kennedy, Rauch et al., 1996; Driver & Dolan, 2004; Lane, Chua, & Dolan; 1999; Lane, Reiman, Bradley, Lang, Ahern et al.,

1997b; Morris, Friston, Büchel, Frith, Young et al., 1998a; Sabatinelli, Bradley, Fitzsimmons, & Lang, 2005; Vuilleumier et al., 2001b; Vuilleumier, Richardson, Armony, Driver, & Dolan, 2004). In order to test whether facilitated perception of emotional stimuli varies as a function of attentional demands many imaging studies employed dual task paradigms presenting stimuli either at attended or unattended spatial locations or asking subjects to perform an attention demanding non-emotional task. Akin to EEG-ERP studies imaging results diverge: While some studies have reported that the amygdala`s ability to amplify perception of salient stimuli (e.g., fearful faces as well as emotional pictures) is related to the availability of attentional processing demands (e.g., Keightley et al., 2003; Pessoa et al., 2002a; Pessoa, McKenna, Gutierrez, & Ungerleider, 2002b) other imaging studies have found enhanced activation of the amygdala and visual cortex regions for fearful faces and emotional IAPS pictures in situations where neutral stimuli would otherwise have been ignored (e.g., Lane et al., 1999; Morris et al., 1998; Vuilleumier et al., 2001b, 2004). However, as long as passive viewing and covert emotional evaluation tasks are used the majority of imaging findings using IAPS pictures conform to the view of motivated attention. In those studies enhanced activation in the visual cortex (e.g., Bradley, Sabatinelly, Lang, Fitzsimmons, King et al., 2003; Lang, Bradley, Fitzsimmons, Cuthbert, Scott et al., 1998c; Junghöfer, Sabatinelli, Bradley, Schupp, Elbert et al., 2006) as well as enhanced activation in the amygdala and higher processing regions of the ventral visual processing stream is found for emotionally highly arousing emotional pictures in contrast to neutral pictures (e.g., Lane et al., 1997b; Junghöfer, Schupp, Stark, & Vaitl, 2005; Sabatinelli et al., 2005).

B.3. Selective processing of emotional stimuli and fronto-limbic pathways

Many imaging studies also report an increase of activation in medial prefrontal cortex structures (MPFC) including anterior cingulate cortex as well as parietal cortex regions indicating a stronger impact of emotional than neutral stimulus processing on attention systems involved in directing and maintaining attention to significant target stimuli (e.g., Breiter et al., 1996; Lane, Fink, Chua, & Dolan, 1997a; Junghöfer et al., 2006; Elliot, Rubinsztein, Sahakian, & Dolan, 2000; Vuilleumier, Armony, Driver, & Dolan, 2001a). Activation of medial prefrontal cortex regions has been observed for the processing of a variety of non-verbal and verbal emotional stimuli during a variety of task contexts including tasks where subjects are explicitly asked to generate stimuli with emotional meaning or evaluate them according to their emotional meaning, self-relevance or semantic stimulus attributes (e.g., Cato, Crosson, Gokcay, Soltysik, Wierenga

et al., 2004; Fossati, Hevenor, Graham, Grady, Keightley et al., 2003; Lane et al., 1997a; Phan, Taylor, Welsh, Decker, Noll et al., 2003; Phan, Taylor, Welsh, Ho, Britton et al., 2004; see Phan, Wager, Taylor, & Liberzon, 2002 for metaanalysis).
Together, the results suggest a stronger impact of fronto-limbic brain circuits in explicit and controlled emotional processing and agree with the view of two cortico-limbic pathways in the modulation of selective processing of affective stimuli: Via its direct reciprocal connections with the sensory cortex the amygdala can amplify sensory processing at early stages of stimulus processing by guiding stimulus-driven attention for further stimulus encoding. Alternatively, the amygdala and the MPFC can further select or suppress the processing of emotional significant information in accordance with current task and behavioural demands (e.g., Elliot et al., 2000; Lane et al., 1997a).

Chapter 3 presents functional imaging data obtained while healthy subjects passively viewed highly arousing emotional and low arousing neutral adjectives. In contrast to many of the prior imaging studies, a passive viewing condition was chosen to study emotional word processing as it happens without confounding task effects. Moreover, a passive viewing context resembles a 'natural state of selective attention', where emotional stimuli have been assumed to capture attention spontaneously by means of their motivational significance and in relation to current motivational goals of the individual (Lang et al., 1997a). Several additional aspects that are beyond the scope of this introduction section will be discussed in detail in chapter 3.

2.9. Emotion and Memory

Emotional processing is obligatory for survival. Therefore, it seems adaptive to enhance perception, attention and memory processing of emotional stimuli to ensure that important information is available immediately at initial stimulus encounter and on future occasions. From a bio-informational point of view, emotional information is regarded to be stored in emotional networks. Stored information comprises different aspects of an emotional stimulus including memory associations. Thus, it has been suggested that the processing of emotional stimuli should benefit from better access to memory, deeper encoding and presumably also from better consolidation of emotional stimuli in memory (e.g., Bradley, 1994). Emotional memory is one of the best documented phenomena in the emotion literature. Memory enhancing effects have been demonstrated for a variety of experimental stimuli including emotional words, pictures, film clips and autobiographical events (e.g., see Bradley, 1994; Kensinger, 2004 for an overview).

Using standardized IAPS picture stimuli memory enhancing effects have been studied systematically in behavioural studies by Margaret Bradley and colleagues (Bradley, 1994; Bradley, Greenwald, Petry, & Lang, 1992).

In general, findings reveal that healthy subjects are more likely to remember emotional than neutral stimuli, specifically when emotional stimuli are rated as highly arousing (e.g., Bradley, 1994; Bradley et al., 1992 for pictures, Sharot & Phelps, 2004 for words). Moreover, the memory advantage for high-arousal stimuli appears to be stronger when memory is tested for long retention intervals (e.g., hours, month or years) than for short retention intervals (e.g., immediately after stimulus encounter) (e.g., Bradley, 1994; Sharot et al., 2004). Better recall of emotional events at longer retention intervals has been interpreted to reflect enhanced memory consolidation processes (e.g., Cahill, Prins, Weber, & McGaugh, 1994; Hamann, 2001 for review; McGaugh, 2000). However, recent studies have also found better recognition of verbal and nonverbal emotional material than neutral material after short delays (e.g., < 15 min) suggesting an immediate impact of emotion on memory encoding processes (e.g., Hamann & Mao, 2001; Kensinger & Corkin, 2004).

There are at least three main stages in the formation of declarative memories (see Hamann, 2001 for an overview): Stimulus encoding is related to the initial stage of stimulus encounter in which memory representations are created from a received stimulus. After stimulus encounter, post encoding processes are required to make these memory representations permanent. This stage has been termed memory consolidation. Consolidation is a gradual process for which an extended period of time is necessary to form a permanent memory trace so that initial memory representations become resistant to loss and thus can be retained more than momentarily. The third stage is retrieval or recall of stored information from long-term memory.

2.9.1. Empirical research

Knowledge about the neural mechanisms underlying emotional memory processes has benefited much from neuroimaging research and EEG-ERP studies investigating emotion effects at different processing stages including stimulus encoding and retrieval. In the following I will refer mainly to studies investigating the impact of emotion on stimulus encoding and later memory performance. This is because of the stronger relevance of these studies for the current experiments described in chapter 2 and 3.

A. EEG-ERP studies on emotional memory

EEG-ERP studies using IAPS pictures show that better memory for highly arousing unpleasant and pleasant pictures is associated with deeper stimulus encoding as indicated by enhanced late positive potentials (LPP) for emotionally arousing pleasant and unpleasant pictures during picture encoding (e.g., Dolcos et al., 2002; Palomba et al., 1997; see in detail in chapter 2). The result accord with assumptions derived from the bio-informational theory suggesting that emotional information has privileged access to processing resources, possibly leading to better memory formation (e.g., Dolcos et al., 2002).

B. Neuroimaging studies on emotional memory

Findings of better emotional memory change considerably when studied in neurological patients suffering from brain damage involving the amygdala. These patients show deficits in recalling highly arousing unpleasant as well as pleasant emotional words, pictures and stories at immediate and long term retention intervals. On the contrary memory for emotionally valent but low arousing items is preserved and comparable to memory performance of normal control subjects or patients with selective damage to the hippocampus (e.g., Hamann, Cahill, McGaugh, & Squire, 1997; Hamann, Lee, & Adolphs, 1999; Phelps & LaBar, 1998; Phelps, LaBar, Anderson, O'Connor, Fulbright et al., 1998).

The possibility to learn, retain and remember factual and contextual information depends on the integrity of the medial temporal lobe memory system (MTL). The MTL comprises a couple of brain structures located in the medial temporal lobes. It consists of the hippocampus and adjacent, anatomically related cortex areas, including entorhinal, perirhinal, and parahippocampal areas (e.g., Squire & Knowlton, 2000). Moreover MTL regions are tightly connected to the amygdala via reciprocal connections. By virtue of its widespread and reciprocal connections with the amygdala the hippocampus can influence amygdala activity when emotional stimuli are encountered. The amygdala in turn modulates the activity of the hippocampus to bolster the encoding and storage of emotional stimuli (LeDoux & Phelps, 2000b; Phelps, 2004).

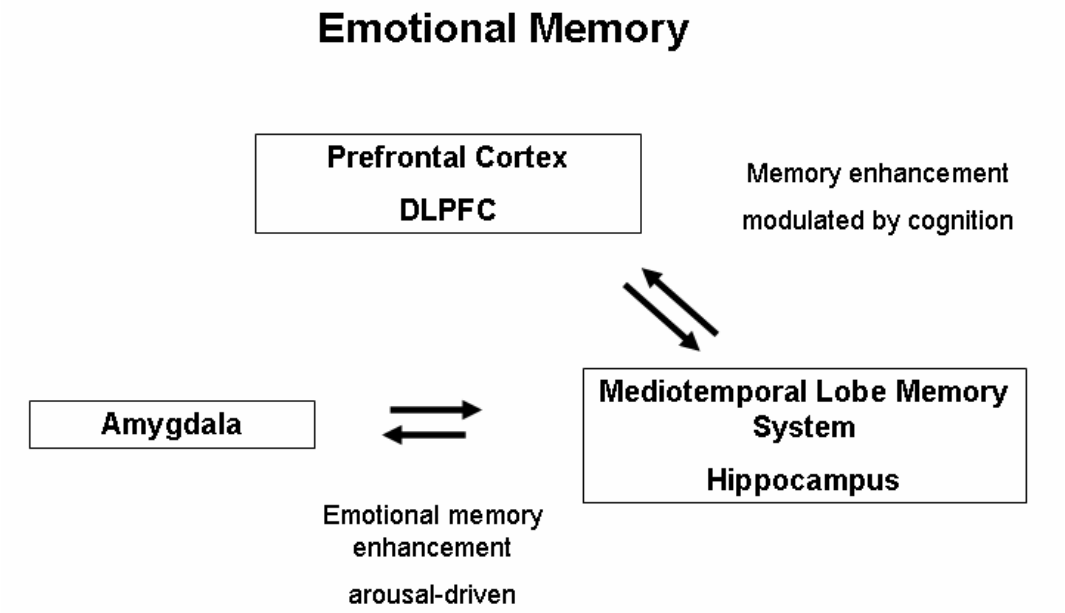
Complementing findings in amygdala damaged patients, imaging studies investigating healthy subjects provide evidence that the amygdala modulates emotional memory by enhancing stimulus encoding and consolidation processes in the MTL. Several studies have found that better recall of highly arousing emotional stimuli is associated with stronger activation of the amygdala (e.g., Canli, Zhao, Brewer, Gabrieli, & Cahill, 2000; Canli, Zhao, Desmond, Glover, &

Gabrieli, 1999) and adjacent MTL regions (e.g., anterior parahippocampus and the hippocampus) for these items during successful encoding (Dolcos, LaBar, & Cabeza, 2004; Hamann, Ely, Grafton, & Kilts, 1999; Kensinger et al., 2004; Kilpatrick & Cahill, 2003). Some of these studies have shown that greater activity of the amygdala and MTL regions at study is positively correlated and predictive of better recall of highly arousing emotional stimuli (Hamann et al., 1999; Kensinger et al., 2004; Kilpatrick et al., 2003). Using structural equation models, Kilpatrick and colleagues (2003), for instance, demonstrated that during encoding of emotionally arousing information, the amygdala exerts a greater influence on the hippocampal system than vice versa. This amygdala mediated memory enhancement may appear relatively automatic to guarantee an immediate impact of emotion on memory encoding processes and has been shown to covary positively with emotional arousal ratings (e.g., Canli et al., 2000; Hamann et al., 2001; Kensinger et al, 2004). For low arousing emotional stimuli (e.g., unpleasant words), Kensinger (2004) has found stronger encoding related activation in the hippocampus and the inferior prefrontal cortex (BA 9 and BA 46) for unpleasant words that would later be correctly remembered. Differential encoding of emotional stimuli varying in emotional arousal corroborate theoretical assumptions propagating that emotional memory processes are modulated by two distinct systems: An arousal-driven, implicit emotion system relying primarily on activation of the amygdala and its influence on medial temporal lobe memory systems (McGaugh, 2000) and a cognitive system relying on the hippocampus and its projections to the lateral prefrontal cortex involved in remembering the 'cold hard' declarative facts of emotional stimuli and their context (e.g., Bechara, Tranel, Damasio, Adolphs, Rockland et al., 1995; Davidson, Jackson, & Kalin, 2000; LeDoux, 1998, 2001). The two neural systems thought to modulate emotional memory are shown in Figure 10 on the next page.
For an overview on neuroimaging studies of emotional memory including both encoding and retrieval effects of emotional stimuli the reader may also refer to excellent review articles (e.g., Hamann, 2001; LaBar & Cabeza, 2006; Phelps, 2004).

Whether highly arousing emotional words in contrast to neutral low arousing words are retained more than momentarily when words are viewed passively was tested by way of surprise free recall tests in two experiments presented in chapter 2 and chapter 3. So far, the majority of behavioural, EEG and imaging studies have used designs in which subjects were explicitly instructed to remember emotional and neutral stimuli at study. Whether arousing emotional words are spontaneously remembered better without any instruction that bolsters deep stimulus

encoding thus may be of interest with regard to both theoretical assumptions and empirical research.

Figure 10: *Two routes of emotional memory.*



3. Overview on the current experiments

The bio-informational theory of emotion provides a basis for systematic emotion research. It makes a variety of assumptions concerning the organization of emotion, the impact of emotion on perception, attention, memory and emotional responses. These assumptions have been reviewed in detail in this chapter. Empirical research has been described showing very wide support for this model. The purpose of the current doctoral thesis is to extend this body of research to the processing of emotional verbal material by testing hypotheses and assumptions derived from the bio-informational theory and prior empirical findings.

Clearly, the first step in addressing emotional word processing from a two-dimensional view of emotion is to test whether the postulated, principal motivational organization of emotion is reflected in evaluative judgements of emotional words. To this end, a large set of emotionally evocative and neutral adjectives covering a broad range of emotional and neutral contents was collected. Evaluative judgements were obtained from 45 student subjects, who rated the words on dimensions of valence and arousal using the SAM rating scales. The study (study 1) presented

in chapter 1 will give a detailed overview on the dataset and the distribution of normative word ratings in the two-dimensional affective space of valence and arousal.

Chapter 2 (study 2) investigates the cortical correlates of motivated attention in the processing of highly arousing emotional and neutral adjectives. No explicit instruction to attend to a specific word category was given to elucidate whether briefly and repeatedly presented emotional words capture and guide selective attention spontaneously. Words were presented randomly in rapid streams using rapid serial visual presentation (RSVP). Two different processing speeds (3 Hz and 1 Hz) were employed to study the impact of attentional processing demands on affective modulation of early and late brain potentials. Furthermore, memory performance was tested by a surprise free recall test to investigate the memory enhancing effect of emotion.

Chapter 3 (study 3) aims to delineate brain structures involved in selective processing of highly arousing emotional adjectives in comparison to neutral adjectives. Event-related fMRI was used to detect spontaneous perceptual changes associated with silent reading of randomly presented unpleasant, pleasant and neutral adjectives. Again no instruction to attend to a specific word category was given and memory was tested by way of a surprise free recall test at the end of the experiment.

Chapter 4 (study 4) investigates the hypothesis of motivational priming. Affective modulation of the defensive startle reflex was assessed while subjects covertly evaluated highly arousing unpleasant, pleasant and neutral adjectives. Visually evoked potentials (VEPs) of the foreground words, as well as the acoustically elicited startle evoked potentials and the electromygrophically recorded startle blink reflex were examined.

4. General considerations

In each experiment emotional and neutral adjectives were selected on the basis of normative word ratings described in chapter 1. Motivational engagement in the processing of emotional stimuli has been considered as well as repeatedly shown to be highest for emotional stimuli rated as highly arousing (e.g., Lang, 1997a). Thus, unpleasant and pleasant adjectives obtaining the highest normative arousal ratings were selected and contrasted against a set of low arousing neutral adjectives. Unpleasant and pleasant adjectives were carefully matched on dimensions of emotional arousal as not to confound emotional valence effects with differences in emotional

arousal. Each experiment comprised a slightly different set of highly arousing emotional and low arousing neutral adjectives to utilize as many of the collected adjectives as possible. The fMRI experiment described in chapter 2 contained adjectives that were used in the other two experiments as well. These adjectives included the most arousing unpleasant and pleasant emotional adjectives. In addition, emotional and neutral word categories were controlled for mean word-length, word frequency as well as concreteness in each experiment, separately. Processing differences between words varying along these three dimensions have been reported in the language literature. For instance, word recognition varies systematically with word length and word frequency yielding faster recognition times for short words or words with higher word frequency (e.g., Balota, Cortese, Sergent-Marshall, Spieler, & Map, 2004; Hauk & Pulvermüller, 2003). Moreover, word length and word frequency have independent as well as additive effects on amplitudes of ERP components (e.g., Hauk et al., 2003) and brain activation patterns (e.g., Fiebach, Friederici, Müller, & von Cramon, 2002). Differential effects including differences in hemispheric modulation patterns for abstract and concrete words on lexical decision and semantic word processing have also been attested in behavioural, ERP and neuroimaging studies (e.g., Kiehl, Liddle, Smith, Mendrek, Forster et al., 1999b; West & Holcomb, 2000). Regarding word-type and semantic category effects, neurolinguistic research suggests that words of different grammatical classes such as verbs and nouns as well as words referring to different semantic categories (e.g., living versus non-living categories) are represented and stored differently in the brain (e.g., Damasio & Tranel, 1993; Dehaene, 1995; Pulvermüller, Lutzenberger, & Preissl, 1999). Results have been based primarily on studies using verbs and nouns. Concerning emotion studies nouns as well as adjectives have been used (Bernat, Bunce, & Shevrin, 2001; Bradley, Mogg, & Williams, 1994; Cacioppo, Crites, & Gardner, 1996; Fosatti et al., 2003, Hamann & Mao, 2002; Naumann, Bartussek, Diedrich, & Laufer, 1992; Shapkin, Gusev, & Kuhl, 2000; Ortigue, Michel, Murray, Mohr, Carbonnel et al., 2004). EEG and neuroimaging evidence for systematic differences between emotional adjectives and emotional nouns has so far not been reported. In fact, some studies have not reported the grammatical class of the words (e.g., Knost, Flor, Braun, & Birbaumer, 1997; Williamson, Harpur, & Hare, 1991) or used mixed lists of adjectives and nouns (e.g., Anderson et al., 2001; Waters, Lipp, & Cobham, 2000). Semantic differential techniques as well as studies comparing evaluative ratings from semantic differential techniques and SAM measures employed rating scales consisting exclusively of adjectives (e.g., Hamm et al., 1993; Osgood et al., 1957). In clinical research, adjectives scales are utilized for the measurement of emotion and affect, bodily symptoms as well as for the measurement of personality traits and states. Moreover, we often use adjectives to

make nouns more intense (Dixon, 1999) (e.g., the brutal murder, the happy birthday) and most importantly to express our emotional and motivational states (e.g., happy, sad, thirsty, hungry, sick).

5. Methodological considerations

Methodologically, event-related brain potentials (ERP) as well as event-related fMRI measures have proven suitable means to examine information processing as it occurs when subjects passively or actively attend to a stream of incoming stimuli such as pictures or words. EEG-ERP methods provide excellent temporal resolution and give insight in the time-course of stimulus processing within milliseconds. Event-related fMRI designs are sensitive to detect small changes in regional cerebral blood flow (rCBF) with a reliable spatial resolution. However, the temporal resolution is limited to the temporal characteristics of the hemodynamic response function (hrf) requiring at least 1 - 2 seconds before reaching its peak maximum. Nevertheless, event-related fMRI designs include a variety of advantages in contrast to blocked fMRI designs, especially when interested in effects of emotion on initial stimulus processing. Blocked stimulus designs are sensitive to detect tonic changes in hemodynamic brain responses between different blocks of stimuli. By contrast, event-related fMRI designs are sensitive to detect subtle changes in brain activation associated with stimulus-locked, perceptual processing (Henson, 2003; Kleinschmidt, Buchel, Zeki, & Frackowiak, 1998). In event-related fMRI designs akin to EEG-ERP methods, any difference in mean signal change reflects dynamic changes elicited during individual trials of emotional and neutral words. In addition, habituation of emotion effects is most prominent in blocked stimulus presentation designs (Breiter et al., 1996). In event-related fMRI habituation effects can be avoided by stimulus randomization. Random presentation of different trial-types ensures that the average response of different trial types is not biased by responses of the preceding trial-types.

For a detailed overview on the basic principles of EEG-ERP measures and fMRI techniques the reader may refer to excellent books and reviews (e.g., Picton, Bentin, Donchin, Hillyard, Johnson et al., 1993; Zschocke, 2002).

II. Chapter 1

Study 1: Evaluative ratings of emotional adjectives

1. Introduction

Adjectives are words that modify nouns. Many adjectives describe attributes of objects belonging to living and non-living semantic categories such as people, places, or things. Usually, we use adjectives for the purpose of making the denotative and affective meaning of these objects more specific and more intense (e.g., tall boy, green grass, lovely women, brutal murder) (Dixon, 1999) as well as to express our own feelings. In German language, adjectives can be used in a predicative or attributive manner (Dixon, 1999).

Emotion studies using concrete pictorial material usually select pictures from standardized picture sets such as the IAPS picture set (see pp. 9 - 10 in the General Introduction section). The IAPS provides normative subjective ratings of emotional valence and emotional arousal for a wide range of emotionally evocative and neutral picture contents that can be used as a measurement standard across studies and laboratories. These normative IAPS ratings show a characteristic distribution in affective space thought to reflect the bi-motivational organization of emotion along the major dimensions of valence and arousal (e.g., Lang et al., 1997b). Concerning language stimuli, a similar set of standardized emotional and neutral words has been collected for English words (ANEW) (Bradley et al., 1999b). For German words standardized word sets are still lacking constraining the comparability of findings across studies and laboratories.

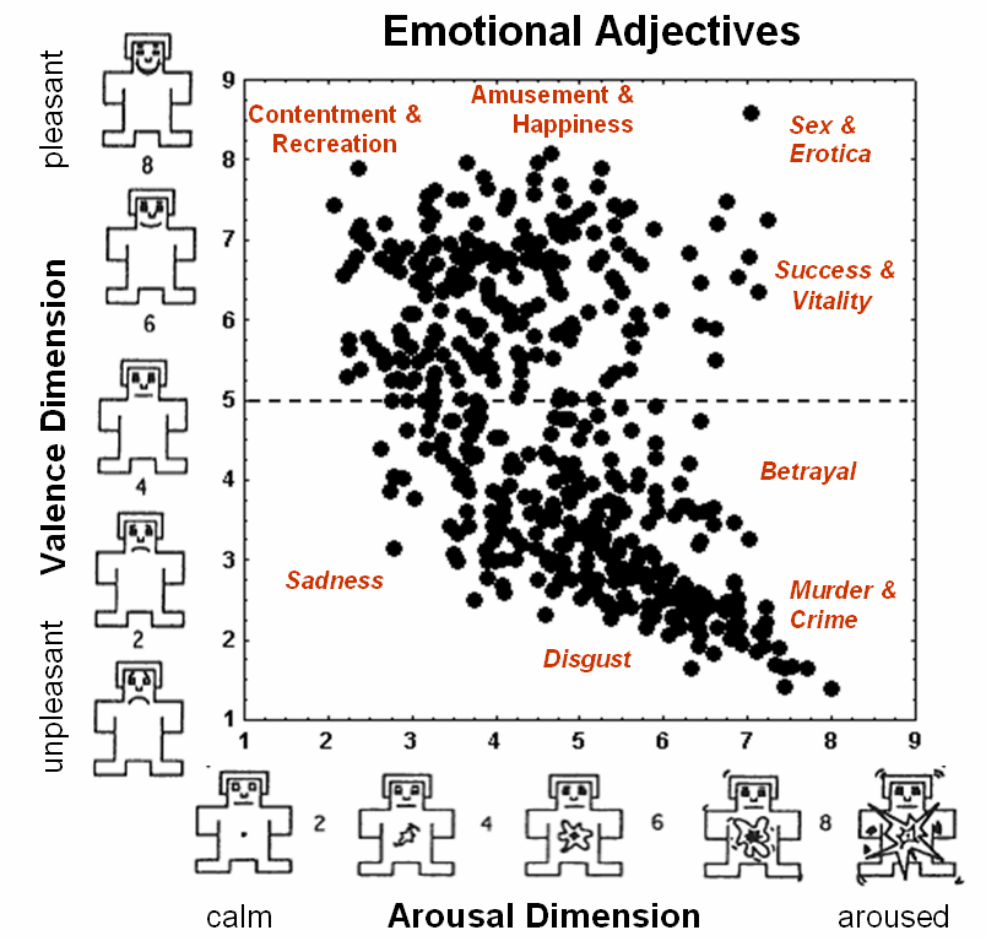
The primary purpose of the following project was to provide a corpus of emotionally evocative and neutral German adjectives and respective normative student ratings of valence and arousal, that can be used as a measurement standard for the current studies of emotional word processing. To this end about 1000 adjectives were collected. Adjectives were selected from different sources including literature books, magazines, newspapers and the handbook of German word norms (Hager & Hasselhorn, 1994). From these 1000 adjectives, 486 adjectives were selected. These 486 adjectives were then randomly assigned to four different adjectives lists, each list containing 243 adjectives. Affective ratings of valence and arousal were acquired from 45 student subjects (26 females, 19 males, mean age: 25.7 years) of the University of Konstanz for each adjective, respectively, using the Self-Assessment Manikin (SAM) affective rating system. Both paper-pencil versions and computerized versions of the SAM were used. In both versions

subjects were asked to rate each adjective separately for valence and arousal, using 9- point valence and arousal scales. The SAM has been used for the calibration of IAPS pictures, ANEW words and emotional sounds (IADS) and has been described in detail in the General Introduction section (pp. 7 - 9). For emotional adjectives, the detailed instruction of the SAM ratings as used for the adjective ratings in the sample of German students is presented in the appendix section together with the whole corpus of adjectives and respective mean valence and arousal ratings.

2. Distribution of emotional and neutral adjectives in Affective Space

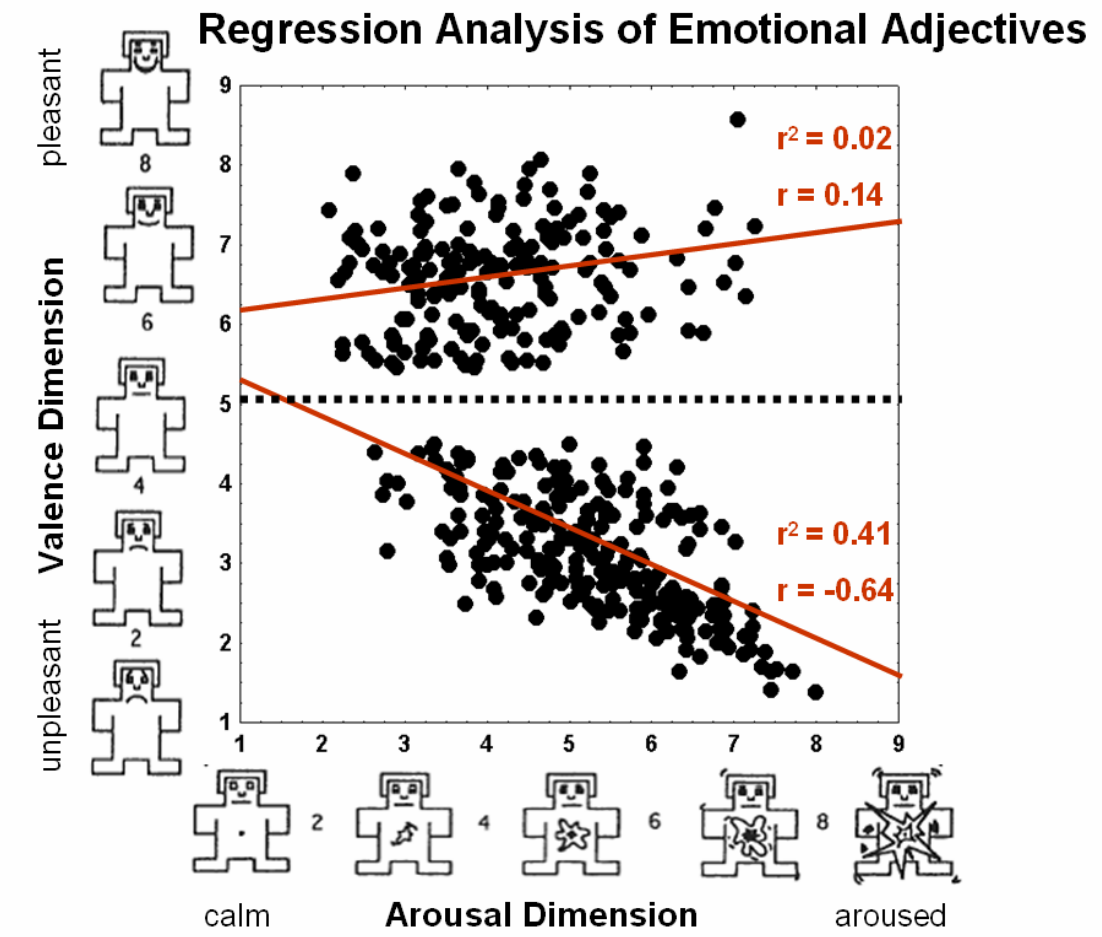
When each adjective is plotted according to its normative mean valence and arousal ratings the adjectives show a typical u-shaped distribution in the two-dimensional affective space. As apparent in Figure 1, the adjectives elicited emotional reactions including the entire range of the valence (y-axis) and arousal (x-axis) dimensions – varying continuously from extremely unpleasant to extremely pleasant and from extremely calm to extremely arousing. Adjectives rated as neutral did not attain the high levels of emotional arousal associated with either pleasant or unpleasant adjectives. These neutral words are located between the upper, pleasant and lower, unpleasant arm of the valence dimension and cluster at the calm end of the arousal dimension.

Figure 1: *Affective Space of emotional adjectives*
Adjectives are organized in a two-dimensional affective space, defined by normative ratings of valence and arousal. Normative ratings were acquired from 45 healthy student subjects using the SAM (see x- and y-axis of the graph, respectively). The adjectives vary across a range of semantic categories, printed in red font, with adjectives belonging to categories of sex and crime having the highest valence and arousal ratings.



The resulting affective distribution of adjectives shares several important characteristic features in common with the distribution of IAPS pictures reported for evaluative SAM ratings of student subjects (see also in the General Introduction): Akin to IAPS pictures, adjectives addressing erotic and exciting as well as threatening contents obtained the highest valence and arousal ratings. These specific emotional contents have been hypothesized to reflect strong appetitive and defensive motives of high evolutionary significance (Bradley et al., 2000; Lang et al., 1997a). Second, the covariation between arousal and valence appeared to be stronger for unpleasant adjectives than for pleasant adjectives. Indeed, as reported for IAPS picture sets, regression lines relating arousal to unpleasant or pleasant valence differed in steepness and slope, respectively (e.g., Ito et al., 1998b). As shown in Figure 2, the regression line for unpleasant adjectives is steeper than that for pleasant adjectives. Akin to the IAPS system, unpleasant adjectives cluster at higher levels of arousal whereas pleasant adjectives are distributed fairly evenly across the valence and arousal dimension. In other words, whereas highly pleasant adjectives or pictures can be either highly arousing or low arousing, highly unpleasant adjectives or pictures are always rated as highly arousing. There exist no highly unpleasant and low arousing pictures or adjectives (Lang et al., 1997b).

Figure 2: *The **'positivity offset'** and the **'negativity bias'** as predicted by regression lines relating arousal to pleasant adjectives (valence > 5.5) and unpleasant adjectives (valence < 4.5). Neutral adjectives with valence ratings of 4.5 < x < 5.5 were omitted from regression analyses. (Regression line for unpleasant adjectives: y = 5.3-0.41; p <.001; Regression line for pleasant adjectives: y = 6.3+0.08; p =0.5).*



The comparison between pictures and adjectives evidently shows that a '*negativity bias*' as well as a '*positivity offset*' is inherent in the evaluative ratings of emotional adjectives, as well (see also on pp. 10 - 11 in the General Introduction). Similar characteristics concerning a '*positivity offset'* and '*negativity bias*' in the distribution of affective words have also been reported for English words (Ito et al., 1998a). Together, the results suggest that emotional evaluation is biased either toward approach or defense. Whereas the appetitive system appears to be more engaged at low and moderate levels of arousal (*'positivity offset'*), stronger responses of the defense system can be expected at very high levels of arousal ('*negativity bias*') (e.g., Cacioppo, 2004; Cacioppo et al., 1997; Ito et al., 1998b, 2005). Some authors have explained this bias in emotional evaluation from an evolutionary point of view according to which these differences in

responsitivity of the appetitive and defensive motivational system support an organism's survival. At moderate levels of arousal, a 'positivity offset' motivates individuals to approach and explore the environment for obtaining knowledge about novel environmental situations and their potentially survival protecting and survival threatening consequences. By contrast, a 'negativity bias' may guarantee responding rapidly and adaptively with attack, defense or withdrawal when confronted with highly arousing stimuli that threaten survival (Cacioppo, 2004; Ito et al., 2005).

The fact that emotional ratings of pictures and adjectives show such a highly similar and characteristic distribution in affective space emphasizes the view that emotional reactions elicited by pictures or by words share a common biological basis that has been supposed to have its origin in two motivational neural brain systems, appetitive and aversive, with emotional arousal predicting the activation of either the appetitive or aversive system (e.g., Lang, 1979; Lang et al., 1997a, b).
A full list of the adjectives as well as mean valence and arousal ratings of the 45 student subjects can be found in the appendix section.

How, when, and where in the brain emotional adjectives are processed and evaluated according to their motivational significance is the focus of the experiments described in the following chapters. Using the adjectives described here, one has the opportunity of selecting subsets of words whose distribution of valence and arousal is well known from normative ratings, thus permitting objectivity and comparability of findings across experiments, methods and subjects.

III. Chapter 2

Study 2: Emotion and Motivated Attention: Time course of emotional word processing and the interaction with selective attention - Insights from early and late ERP potentials

1. Introduction

The presence of emotional stimuli can shape human information processing in many ways. Of central concern is how and when in the processing stream discrimination of affective from neutral stimuli is likely to occur. Theoretically, it has been argued that our perception is especially tuned to preferentially detect and discriminate emotionally relevant stimuli from neutral ones (e.g., Lang et al., 1997a). In this view, emotionally unpleasant and pleasant stimuli are processed in a facilitated manner because they spontaneously arouse and capture the viewer's attention. This 'stimulus-driven', 'natural' or 'motivated attention' helps to increase the likelihood with which potentially dangerous or rewarding information can be perceived and subjected to further stimulus evaluation (e.g., Bradley et al., 2000; Lang et al., 1997a). Growing evidence in support of this thesis comes from event-related brain potential studies (EEG-ERP) that investigated the time-course of emotional picture processing. In sum, these EEG-ERP studies have shown that emotional stimuli capture and guide selective attention at different processing stages including perceptual stimulus encoding and stimulus representation in working memory. Although many of these EEG-ERP studies have already been discussed in the General Introduction (pp. 17 - 20), some findings will now be described with respect to their implications for the current ERP study using emotional words.

1.1. Effects of emotion on stimulus perception

1.1.1. Affective modulation of early brain potentials

When subjects passively view or actively attend to a stream of briefly presented stimuli highly arousing emotional pictures and faces compared to neutral ones initially evoke a pronounced relative negative shift in the ERP waveform, the so called early posterior negativity or 'EPN' potential (e.g., Junghöfer et al., 2001; Schupp et al., 2003a, b, 2004b). The selective differentiation between affective and neutral pictures develops as early as 150 - 180 ms after picture onset and is most pronounced for highly arousing pictures over occipito-temporal sensors

at about 250 – 280 ms post picture-onset (e.g., Junghöfer et al., 2001). Larger 'EPN' amplitudes for emotional pictures are obtained when random picture sequences are presented briefly (e.g., 120 ms - 1.5 sec) and subjects have to categorize each stimulus as either unpleasant, pleasant or neutral (e.g., Schupp et al., 2003a, 2004b) or when pictures are presented in rapid serial visual stimulation designs using short stimulus durations of 200 ms and 333 ms (Junghöfer et al., 2001) and subjects simply view the pictures without any explicit instruction to attend to a specific picture category (i.e., passive viewing condition). Affective modulation of the 'EPN' component even occurs when subjects' attention is directed toward a secondary non-emotional task (Schupp et al., 2003b). Together, the findings confirm the hypothesis of 'motivated attention' predicting that emotionally highly arousing stimuli obtain priority in processing by enhancing perception and directing attentional resources.

However, it is still controversially debated if affective differences in early perceptual processing can also be expected for other visual inputs such as emotional words. Words and pictures differ in many perceptual and conceptual stimulus characteristics (e.g., Glaser & Glaser, 1989). These differences may pertain to the processing of emotional meaning (e.g., DeHouwer & Herrmans, 1994) and may influence the time course at which emotion effects of concrete, pictorial and abstract, verbal meaning representations can be expected. Reviewing the EEG-ERP literature on affective word processing provides mixed results. On the on hand, there are studies that failed to find affective differentiation in early time windows suggesting that the emotional connotation of written words may be analyzed relatively later in the processing stream after their meaning has been subjected to higher-level semantic processing and conscious recollection (e.g., Cacioppo, Crites, Bernston, & Coles, 1993; Naumann et al., 1992; Fischler & Bradley, 2006). On the other hand, some studies have found early selection effects. Affective modulation starting in the P1-N1 time window at about 100 – 200 ms and extending to the P2-N2 time window at about 200 - 260 ms after word onset are among the most frequently reported early selective processing effects examined in healthy subjects (e.g., Begleiter & Platz, 1969; Begleiter, Projesz, & Garozzo, 1979; Bernat et al., 2001; Chapman, McCrary, Chapman, & Bragdon, 1978; Chapman, McCrary, Chapman, & Martin, 1980; Schapkin, et al., 2000; Skrandies, 1998; Ortigue et al., 2004) and in clinical patients regarded to have an attentional bias toward either unpleasant, pleasant or specific emotional or disorder-related content words (e.g., Flor, Knost, & Birbaumer, 1997; Kiehl, Hare, McDonald, & Brink, 1999a; Knost et al., 1997; Pauli, Amrhein, Mühlberger, Dengler, & Wiedemann, 2005; Weinstein, 1995; Williamson et al., 1991). Results have been interpreted as evidence for enhanced allocation of attention to (N1) and facilitated stimulus discrimination (P2, N2) of emotionally relevant information in healthy subjects and patients or a

lack thereof in certain patient groups such as psychopaths (Kissler, Assadollahi, & Herbert, 2006 for review). Although these ERP studies demonstrate, that early brain potentials reliably distinguish between affective and neutral words across a variety of different experimental designs, tasks and subjects, the question whether emotional words amplify early perceptual processing in a similar manner as has been demonstrated in ERP studies using emotional pictures and faces remains open. Yet, only one of the reviewed ERP studies has reported early selective differentiation between emotional and neutral words over occipito-temporal electrode sites (Ortigue et al., 2004) indicating enhanced perceptional processing of emotional words in the visual cortex.

1.1.2. Rapid serial visual presentation

Researchers have devised several paradigms to examine the impact of emotion on perception and attention. The 'rapid stream stimulation' (RSS) (e.g., Hinojosa, Martin-Loeches, Casado, Munoz, Fernandez-Frias et al., 2001; Rudell, 1992 for an overview) or 'rapid serial visual presentation' paradigm (RSVP) (e.g., Junghöfer et al., 2001; Potter, 1984) provides a promising methodological approach to study the effects of selective processing of different types of stimuli such as pictures or words and appears most suitable for EEG-ERP studies. In a typical rapid stream design words or pictures are presented sequentially without any interstimulus interval. Concerning cognitive research, RSVP designs have shown that pictures can be correctly identified and named at stimulus presentation rates of up to 8 items per second and word naming occurs even faster at rates of up to 12 items per second (e.g., Potter, 1975; Potter et al., 1987). It turns out that even at early levels of perception meaning can be extracted rapidly from streams of words or pictures. Using emotional words several behavioural RSVP studies have shown that emotional words are detected more accurately than neutral words although our capacity to attend to a stream of incoming stimuli is limited (e.g., Anderson, 2005; Anderson et al., 2001; Keil & Ihssen, 2004).

1.1.3. The recognition potential: An ERP signature of early semantic processing

Language research has applied rapid serial presentation methods to investigate the neural correlates of early perceptual word processing. When words are presented in rapid continuous streams meaningful words relative to meaningless verbal stimuli (e.g., pseudowords, non-words, and letter strings) elicit an early posterior negativity potential at latencies of about 200 ms and

peak maxima at about 250 ms after stimulus onset. This so called 'recognition potential' or 'RP' potential (Rudell, 1992) has been interpreted as a signature of early semantic processing (e.g., Hinojosa et al., 2001; Hinojosa, Martin-Loeches, Munoz, Casado, & Pozo, 2004; Martin-Loeches, Hinojosa, Gomez-Jarabo, & Rubia, 2001; Rudell, 1992). Because the potential is maximally pronounced over parieto-occipital electrode sites early semantic processing has been closely related to perceptual word processing in the visual cortex. The proposal of the 'RP' potential as a marker of early semantic processing occurring automatically as soon as a meaningful word has been perceived (Hinojosa et al., 2004) is supported by behavioural and eye movement studies showing that lexical (e.g., word-form) and content-based (semantic meaning) information come together in the identification of a printed word at about 250 ms (e.g., Rubin & Turano, 1992; Sereno et al., 1998). Most research concerning the 'RP' potential has presented words at an SOA of 275 ms (e.g., Hinojosa et al., 2001 for an overview). However, the 'RP' potential is also elicited by words presented at faster stimulation rates of 100 ms (Rudell, 1992) and is largest for attended compared to unattended words (Rudell & Hua, 1996). While the 'RP' potential has been studied using verbal material most frequently there are also studies examining the 'RP' on picture and face stimuli (Rudell, 1991; Hinojosa, Martin-Loeches, Gomez-Jarabo, & Rubia, 2000). So far, the 'RP' potential has been investigated in rapid stream stimulation (RSS). RSS is similar to rapid serial visual presentation (RSVP) used in emotion and cognitive research. In RSS stimuli are presented in alternating sequences of target stimuli and a couple of six or seven control stimuli. Target stimuli include different types of word stimuli (e.g., animal names, abstract and concrete words, pseudowords and random letter strings). Control stimuli are devoid of meaning, contain no linguistic properties and are carefully matched with target stimuli for physical attributes such as stimulus length and size. No 'RP' potential is elicited by control stimuli. Because the 'RP' potential has been found for meaningful stimuli only but not for meaningless control stimuli or simple stimuli such as auditory clicks, light flashes or tones, the potential has been termed 'recognition potential'.

1.1.4. The recognition potential (RP) and the early posterior negativity (EPN)

Apart from terminology, modulation of the 'RP' potential to meaningful stimuli and the modulation of the so called 'EPN' potential reported in affective picture studies seem to reflect similar cognitive processes. Both potentials can be elicited in RSVP/RSS designs, have similar latencies and spatial topography, are sensitive to manipulations of attention and are reliably modulated by the semantic and affective content of briefly presented visual stimuli. Moreover

source analysis techniques revealed similar neural generators for the 'RP' and 'EPN' potential suggesting that both potentials originate from brain activity in extrastriate visual cortex areas (e.g., Hinojosa et al., 2000, 2001; Junghöfer et al., 2001). Extrastriate cortex areas play a crucial role in object recognition, with neurons responding selectively to words and other types of meaningful stimuli such as faces (e.g., Cohen, Dehaene, Naccache, Lehericy, Dehaene-Lambertz, et al., 2000; Kanwisher, McDermott, & Chun, 1997; Nobre, Allison, & McCarthy, 1994; Puce, Allison, Asgari, Gore, & McCarthy, 1996). Moreover, these visual brain areas are closely connected to the amygdala (Amaral et al., 1992). Notably imaging studies suggest that the amygdala facilitates the perception of emotional words and pictures via its direct feedback projections to extrastriate and visual cortex regions (e.g., Isenberg, Silbersweig, Engelien, Emmerich, Malavade et al., 1999; Lane et al., 1999; Sabatinelli et al., 2005; Tabert, Borod, Tang, Lange, Wei et al., 2001).

Although both brain potentials have been termed differently and so far have been studied in different research fields it appears plausible to assume that 'early posterior negativity' potentials will be good candidates to study early selective processing of emotional words. If a word's emotional connotation can be directly accessed at an early perceptual level (as suggested by the research on the 'RP' potential) this should be reflected in an early posterior negativity potential being more pronounced for emotional compared to neutral words. Second, as a process reflecting stimulus-driven, 'natural' or 'motivated attention' as demonstrated by research on the 'EPN' potential this early selection priority for emotional words should occur spontaneously, irrespective of whether attention is limited due to incoming new information and irrespective of subjects` prior intention to attend to the emotionality of the presented words.

1.1.5. Mechanisms of selective attention

Concerning the impact of attention on stimulus perception, two stage competition models of visual attention propose that our capacity to attend to an array of stimuli is limited (e.g., Chun et al., 1995; see also General Introduction pp. 16 - 17). Thus, stimuli have to compete for limited attentional resources. Prior research has shown that when participants have to detect stimuli in rapid streams there is a transient impairment of awareness for a subsequently presented second target if it occurs 200 - 500 ms after the first target stimulus. This suppression of awareness has been called the 'attentional blink' (Raymond, Shapiro, & Arnell, 1992) and is due to a postperceptual impairment arising after the second stimulus has been perceived. In EEG-ERP studies, ERP components reflecting sensory (P1, N1) analysis and semantic analysis as measured

by the N400 potential show no suppression regardless of whether the second stimulus is missed or whether it can be identified, correctly. Suppression of the second target occurs at the time window of the P3 potential, a cortical component reflecting updating of working memory (e.g., Rolke, Heil, Streb, & Hennighausen, 2001; Vogel, Luck, & Shapiro, 1998). Only stimuli that can be correctly identified and attended elicit a P3 potential. The results of these studies suggest that subsequently presented stimuli can be detected, identified and understood momentarily although occuring in close proximity to each other and although attention is limited. However only those stimuli that can be attended to more than momentarily can also be represented in working memory and remembered. In a series of behavioural studies Potter and colleagues have demonstrated this loss of information in memory: At presentation rates faster than 333 ms pictures and words can be identified and named but recall for those stimuli is below chance level (< 50 % correctly remembered items). For instance, only 2.6 words out of 6 words can be correctly remembered. At presentation rates slower than 333 ms – 1000 ms, mean recall performance reaches the standard memory span of 7 +/- 2 items. Then, about 4 words can be correctly remembered when recall performance is tested immediately at very short delays of about 2 - 6 minutes or so (e.g., Potter, 1982, 1993).

To date, behavioural studies using words and EEG studies using pictures have left no doubt that emotional stimuli capture attention in the first 200 ms more efficiently and accurately than neutral stimuli even when presented at the critical time period where attention is limited and stimuli have to compete for perceptual awareness (e.g., Anderson, 2005; Anderson et al., 2001; Keil et al., 2004; Junghöfer et al., 2001). However, none of these studies that used RSVP has tested whether better perceptual awareness for emotional pictures or words also leads to better stimulus encoding and memory consolidation.

1.2. Effects of emotion on stimulus encoding and memory

1.2.1. Affective modulation of late brain potentials

The influence of emotional content on stimulus encoding and memory is well characterized in the literature showing that emotional stimuli, in particular highly arousing ones, are remembered better than neutral ones (e.g., Bradley, 1994; Bradley et al., 1992; Sharot et al., 2004). Recent findings from ERP studies imply that better memory for emotional events is due to deeper stimulus encoding that proceeds *after* the emotional significance of a stimulus has been perceived. All of these studies have used highly arousing pleasant and unpleasant pictures or words, comparatively long stimulus durations of 2 – 6 seconds and deep encoding tasks where

subjects had to evaluate the stimuli according to semantic or emotional attributes or memorize the stimuli for an immediate recall test. The results show that enhanced late positive ERP potentials elicited by emotionally highly arousing stimuli at study are associated with better recall of those stimuli. Visually evoked potential (VEP) effects were most pronounced over centro-parietal electrodes starting in the time window of the P3 potential and / or the late positive component (LPP) at about 500 ms - 800 ms after picture onset or 400 ms - 700 ms after word onset (e.g., for pictures: Dolcos et al., 2002; Palomba et al., 1997; for words: Fischler, Candice, Kemp, & McKay unpublished abstract: http://www.psych.ufl.edu/~Fischler/CM64abstract.html). Late brain potentials such as the P3 and LPP component have proven sensitive measures of cognitive processes associated with enhanced stimulus evaluation, depth of processing and memory updating (e.g., Donchin et al., 1988; Ritter & Ruchkin, 1992). Accordingly, larger P3/LPP amplitudes to emotional stimuli suggest that emotional stimuli lead to deeper processing, deeper evaluation and better organization in memory. However, in all the studies reported above, deep encoding was motivated by task demands. When tasks require no explicit emotional or semantic categorization, studies using verbal material have produced mixed results yielding either no impact of emotion on postperceptual stimulus processing or a stronger impact of emotionally pleasant words. For instance, Leiphart, Rosenfeld, and Gabrieli (1993) failed to find electrophysiological evidence for a modulatory influence of emotion on stimulus encoding. No affective modulation of late positive potentials (P3) occurred when briefly presented emotional words had to be recognized according to perceptual stimulus features. Nevertheless more high than low-emotion words were responded to correctly in a subsequent recognition test which suggests that memory consolidation involves additional processes that take time to develop. Similarly, Naumann and associates (1996) failed to find late ERP potential differentiation when subjects had to discriminate emotionally arousing and neutral nouns according to lexical features.

Investigating the influence of different levels of stimulus processing on emotional processing and its relation to later memory, Ferré (2003) has found different effects of emotional arousal and valence. Pleasant and unpleasant words matched for perceived arousal were processed in a facilitated manner and were better remembered than neutral words when semantically encoded (deep encoding). By contrast, in the shallow encoding condition (subjects had to count vowels) only pleasant words were responded to faster and more accurately and were also better remembered than unpleasant or neutral words. In a similar vein, Kiefer and colleagues (in press) have found that affective adjectives elicit differential brain activation and memory effects depending on the complexity of the encoding task and the affective state of the participants

(Kiefer, Schuch, Schenk, & Fiedler, in press). For degraded stimulus presentations a processing advantage for pleasant adjectives emerged. In the EEG, this processing difference between pleasant and unpleasant adjectives appeared for the N400 component as well as for late positive event-related potentials. Smaller N400 amplitudes are usually interpreted to reflect the ease with which semantic meaning can be integrated in the current context (e.g., Holcomb, 1993; Kutas & Federmeier, 2000). Accordingly, the N400 component was less pronounced for pleasant adjectives than for unpleasant ones. Additionally, enhanced activation in the LPP time window was found for pleasant in contrast to unpleasant adjectives. As reported by Ferré (2003) pleasant adjectives were better remembered in the shallow encoding condition (degraded stimulus presentation). ERP (N400 and LPP) and memory effects covaried with the participants' affective state and were most pronounced for subjects in positive mood.

Findings of better semantic processing as indexed by the N400 brain potential, deeper encoding as indexed by late positive components and better memory for pleasant verbal information at low levels of stimulus encoding have been explained in terms of individual preferences for mood-congruent information. Because healthy subjects show a tendency for positive mood, pleasant information attracts attention more efficiently and leads to deeper semantic integration and stimulus encoding than mood-incongruent unpleasant information (for detailed discussion see Ferré, 2003; Kiefer et al., in press). This positivity bias is more likely to occur in tasks that do not promote deep encoding strategies (Ferré, 2003). Indeed, such pleasure preferences are not restricted to verbal material but have also been reported for pleasant picture stimuli provoking larger P3 potentials than unpleasant and neutral pictures when studied in tasks where subjects are not explicitly asked to evaluate the emotional meaning of the stimuli (e.g., Delplanque et al., 2004).

In sum, the present findings suggest that emotional stimuli capture attention at early levels of perception and guide selective attention during later stages of stimulus processing reflecting further sustained processing of emotional stimuli. Because our capacity to attend to an incoming stream of information is limited only those stimuli that capture attention more than momentarily will be consciously recognized and subjected to a more detailed processing and consolidation in memory (e.g., Chun et al., 1995). Emotional arousal and valence may determine which stimuli are selected for further processing depending on subjects` intention and task demands. Thus, effects of positive valence may dominate in healthy subjects, specifically when processing requires no explicit evaluation of a stimulus for semantic and emotional meaning.

The aim of the present EEG study was to address these assumptions on early and late selection effects for emotional words. To this end, perceptual processing of highly arousing emotional and low arousing neutral adjectives was examined within rapid stream stimulation. Recording event-related brain potentials (ERPs) in rapid stream stimulation has proven a suitable means to study the time-course of emotional processing as it occurs when subjects passively view or actively attend to a stream of incoming stimuli such as pictures or words (e.g., Ihssen, Heim, & Keil, 2004; Junghöfer et al., 2001). To investigate whether emotional words capture attention 'naturally' a passive viewing task was given that required neither any explicit emotional categorization nor any behavioural response of the participants. Words were presented at two different processing speeds (333 ms and 1000 ms). The rate of one word per second was chosen to examine whether emotional words in contrast to neutral words could be attended to and retained more than momentarily at a postperceptual level. If passive viewing promotes a processing bias for emotional, possibly pleasant words, this should be reflected in affective modulation of late ERP potentials (e.g., N400 and LPP) and better recall for pleasant relative to unpleasant or neutral words. To explore the impact of emotion on memory participants were confronted with an unexpected free recall task, 30 minutes after the end of the experiment.

2. Methods

2.1. Participants

A total of sixteen native German speaking student volunteers (8 female, 8 male, mean age: 27 years) from the University of Konstanz participated for either course credit or a financial bonus of 10 Euros in return for participation. All subjects were right-handed as determined by handedness scores on the Edinburgh Handedness Inventory (Oldfield, 1971). Upon interview, participants reported normal or corrected-to-normal vision and no drug abuse, neurological, mental or chronic bodily diseases or medication for any of these. All subjects read and signed a detailed consent form approved by the University of Konstanz Institutional Review Board.

2.2. Stimulus Material

Experimental stimuli consisted of 180 adjectives from three different emotional categories, including 60 highly unpleasant, 60 highly pleasant and 60 low arousing neutral adjectives. Words were selected according to previous, independent ratings of 45 student subjects. Word ratings were obtained on the dimensions of perceived arousal and valence using a standardized

version of the SAM, Self-Assessment Manikin (e.g., Lang, 1980; Lang et al., 1997b). Unpleasant, pleasant and neutral word categories differed significantly with respect to normative valence ratings (M = 2.7, 6.6, and 5.0 for unpleasant, pleasant and neutral contents). Unpleasant and pleasant adjectives did not differ significantly from each other but were significantly more arousing than neutral adjectives (M = 5.7, 5.5, and 3.4 for unpleasant, pleasant, and neutral contents). Mean valence and arousal ratings for unpleasant, pleasant and neutral word categories are shown in Table 1.

Table 1: *SAM mean valence and arousal ratings of pleasant, neutral, and unpleasant adjectives rated by 45 students of the University of Konstanz.*

Mean Valence and Arousal Ratings	Adjectives		
	Pleasant	Neutral	Unpleasant
Valence	6.6 (.11)	5.0 (.07)	2.7 (.06)
Arousal	5.5 (.09)	3.4 (.07)	5.7 (.09)

The range and direction of the SAM ratings are as follows: Valence = 9 (extremely pleasant) to 1 (extremely unpleasant), arousal = 9 (extremely arousing) to 1 (not at all arousing). Standard errors are in parentheses.

2.2.1. Control of additional word dimensions

Concreteness ratings of words were obtained by additional ratings of 31 student subjects (21 females, 10 males, mean age: 29 years) using a nine-point Lykert scale. Processing differences between concrete and abstract words, between high and low-frequent words on latency and amplitude measures of ERP potentials have been attested by a large body of studies that examined early (e.g., 'RP' potential) and late brain potentials (e.g., N400 and LPP) (e.g., Hauk et al., 2003 for review; Rudell, 1999; Rugg, 1990; Polich & Donchin, 1988). Therefore, adjectives belonging to different emotional categories were carefully controlled for these dimensions. Word categories did not differ in concreteness ratings or in word length and word frequency (see Table 2 – Table 4). Word frequency was controlled using frequency counts for written language from the standardized word-database CELEX (Baayen, Piepenbrock, &

Gulikers, 1995). Thus, ERP differences arising from variations in emotional arousal and valence cannot be due to variations in word length, word frequency or concreteness.

Table 2: *Mean concreteness of pleasant, neutral, and unpleasant German adjectives obtained from ratings of 31 student subjects of the University of Konstanz.*

Conreteness	Adjectives		
	Pleasant	Neutral	Unpleasant
	4.5 (.15)	4.6 (.23)	4.2 (.14)

The concreteness ratings ranged from 1 (extremely concrete) to 9 (extremely abstract). Standard errors are in parentheses.

Table 3: *Frequency counts for written language from the standardized word-database CELEX of pleasant, neutral, and unpleasant adjectives.*

Mean Word frequency	Adjectives		
MannW	Pleasant	Neutral	Unpleasant
	14.98 (2.49)	22.53.78 (3.61)	14.52 (3.05)

Standard errors are in parentheses.

Table 4: *Mean word length of pleasant, neutral, and unpleasant adjectives.*

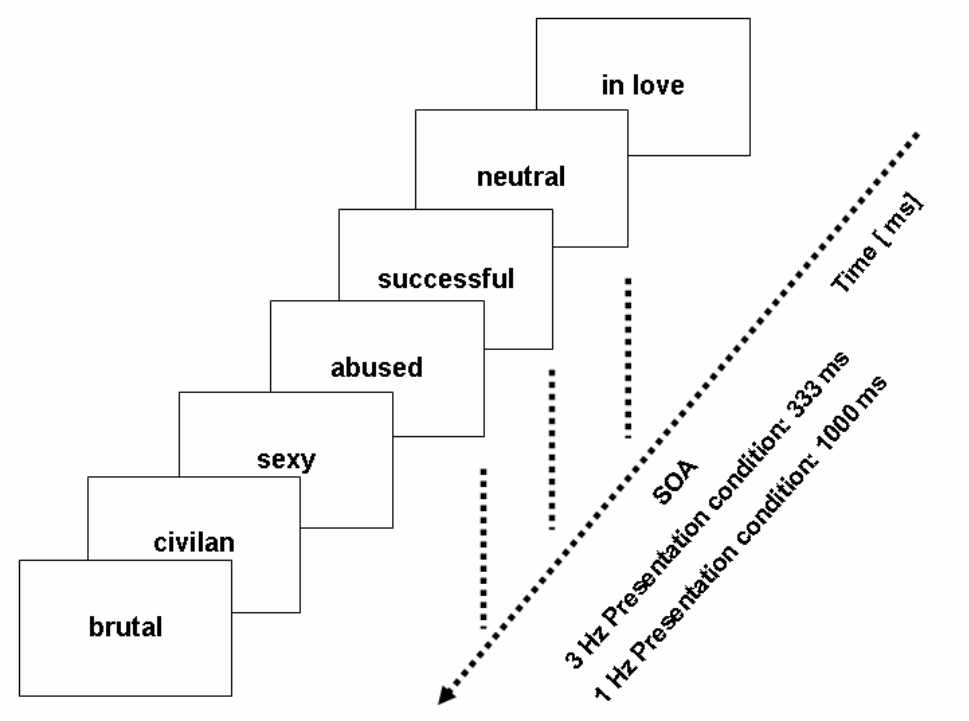
Mean Word length	Adjectives		
	Pleasant	Neutral	Unpleasant
	8.7 (.33)	7.9 (.29)	8.5 (.27)

Standard errors are in parentheses.

2.3. Experimental Design

All words were presented orthographically correct (font size = 40), in black letters (font = 'Times') centered on a 15-inch white computer monitor approximately 1.0 m from the participants' eyes. The experimental design was carefully constructed to eliminate effects due to word repetition, serial presentation, serial testing position, or effects due to predictability of the arousal/valence category of the upcoming words. Adjectives were presented randomly, in ten blocks of a rapid serial visual stream presentation (RSVP). An example of the experimental design is depicted in Figure 1.

Figure 1: ***Experimental Design:*** *Rapid serial visual presentation (RSVP) of emotional and neutral adjectives.*



Each block consisted of a total of 60 unpleasant, 60 pleasant and 60 neutral adjectives. Within one block no word occurred twice. Across blocks words were presented in different random orders to prevent habituation effects due to stimulus repetition or serial order. Adjectives were viewed at two different stimulation rates. In five out of ten blocks adjectives were presented continuously at an SOA of 333 ms (*3 Hz stimulation*) or at an SOA of one second (*1 Hz stimulation*). A rate of three or one word(s) per second resembles stimulus duration employed in RSVP studies using verbal and pictorial stimuli (e.g., Hinojosa et al., 2001; Junghöfer et al.,

2001; Potter, 1982, 1993). For half of the subjects the experimental session either started with the first five blocks comprising the fast, *3 Hz stimulation* conditions or with five blocks comprising the slow, *1 Hz stimulation* conditions.

Experimental runs were generated and controlled by 'Presentation' software (Neurobehavioral Systems Inc.).

2.4. Procedure

After arrival participants were familiarized with the laboratory setting and the experiment was explained to them in general terms. They were questioned with regard to their medical status, their handedness was determined and they signed an informed consent form. Participants were seated in a recliner chair in a dimly lit, sound attenuated room and EEG electrodes were attached.

Participants then were familiarized with the experimental instruction. Words were presented in a passive viewing task. No explicit emotional instruction was given. Subjects were told to focus and attend to the words over the whole viewing time but they received no explicit instruction to pay attention to any particular valence category. At the beginning of the experiment subjects were asked to avoid eye blinks as well as eye or body movements as far as possible.

Thirty minutes after the experiment participants were asked to remember as many of the presented words as they could in an unexpected free recall task. In the free recall task subjects had to categorize each remembered word with regard to its emotional valence as unpleasant, pleasant, or neutral. Word categories were randomized for serial order across subjects. An example of the free recall task is presented in the appendix.

2.5. Physiological Data Collection and Reduction

Electrophysiological data were recorded from 64 channels, using an EasyCap system and NEUROSCAN SynAmps amplifier and software. Vertical and horizontal electrooculograms (EOG) were recorded above and below the left and right eye (VEOG) and lateral to the outer canthus of each eye (HEOG). Raw EEG data were continuously recorded at a sampling rate of 250 Hz and referenced to the Vertex electrode (Cz). The Vertex reference was converted to an average reference offline. During recording impedance was held beneath 5 kΩ. Filtering, artifact rejection and analyses of the ERP-EEG responses followed off line: Early ERP components

were digitally filtered from 0.53 to 40 Hz. The N400 and LPP component were filtered with a time constant of 1 second referring to a low cutoff of 0.1 Hz. Filtered data were corrected for blinks, vertical and horizontal eye movements, using the ocular correction algorithm of BESA (Brain Electrical Source Analysis) software (Ille, Berg, & Scherg, 2002). Semi-automatic artifact rejection excluded signals with amplitudes larger than 150 μV, lower activity than 0.0032 μV in each channel and voltage differences greater than 50 μV between two sampling points. Artifact free EEG data was segmented separately for each word category, block and viewing condition. In the *3 Hz stimulation* conditions EEG data were segmented from 333 ms before word onset until word offset. In the *1 Hz stimulation* conditions data were segmented from 1000 ms before word onset until word offset. In both viewing conditions, the pre-stimulus segment was used for baseline correction before averaging.

2.5.1. Baseline correction in RSVP designs

In RSVP designs visual brain potentials of target stimuli can be analyzed without overlapping activity related to the preceding ERP potentials using the pre-stimulus segment for baseline correction. When stimulus order is counterbalanced across different word categories, as is the case in the present study, no differences in baseline measures are to be expected.

2.5.2. Early visual ERP potentials (3 Hz condition and 1 Hz condition)

Early brain potentials were analyzed as averaged activity within a time window from 200 ms to 280 ms after word onset at sixteen posterior electrodes. The sixteen posterior electrodes were grouped in two channel groups including eight electrode sites on the left hemisphere (TP7, TP9, P5, P7, P9, PO3, O1, and O9) and eight electrode sites on the right hemisphere (TP8, TP10, P6, P8, P10, PO4, O2, and O10). To determine hemisphere differences in affective modulation patterns, effects for left and right hemisphere electrode sites are reported for normalized data according to the procedure suggested by McCarthy and Wood (1985):

$$X_{inew} = (X_{imeas} - \min) / (\max - \min)$$

where X_{inew} is the normalized value at sensor i, X_{imeas} is the measured value at sensor i and max and min are the maximum and minimum across sensors.

2.5.3. Late visual ERP potentials (1 Hz condition only)

A. N400 potential

Single subject individual waveform analysis revealed that amplitudes of the N400 component were most prominent about 360 - 470 ms after word onset at midline centro-parietal electrodes. Inspections of individual topographic maps revealed a local distribution with a right dominant focus. Across subjects the N400 potential could be reliably detected at the following electrodes (Cz, C4, CPz, CP2 and CP4). For statistical analysis these five centro-parietal electrodes were grouped together and the N400 potential was scored by determining the mean voltage activity within a time window from 360 ms to 470 ms after word onset.

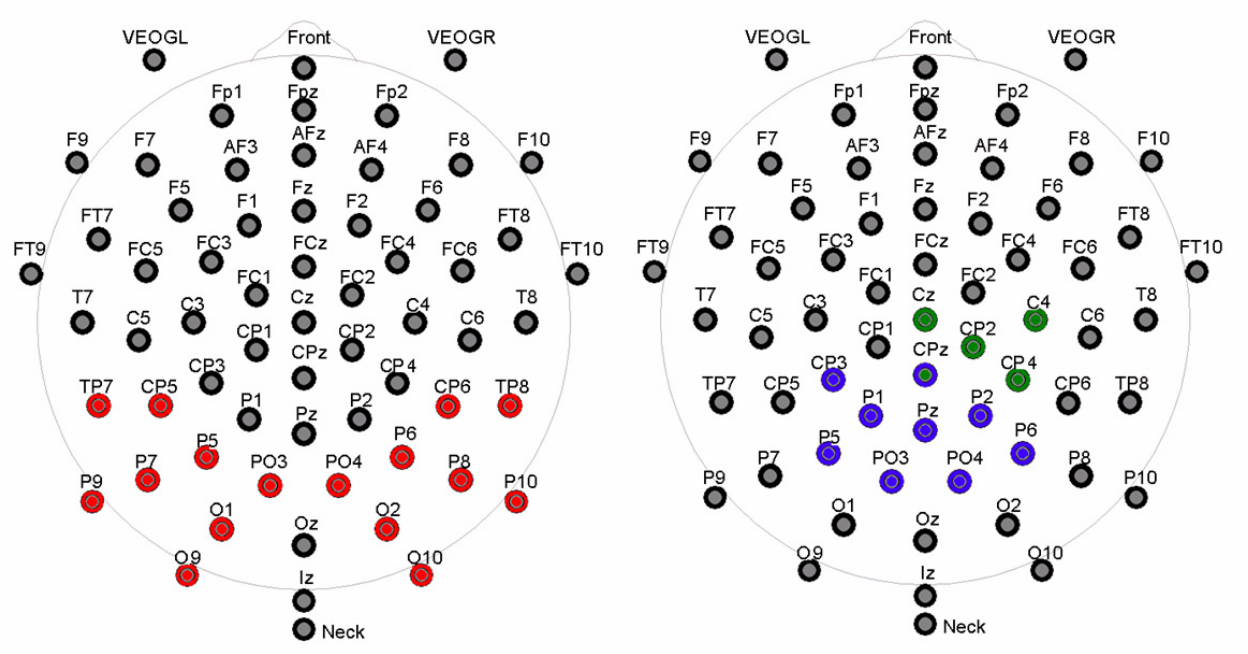
B. Late positive potential (LPP)

In line with findings reported for late positive potentials, adjectives elicited a late positive going brain potential (LPP) that was most pronounced in a time window starting at 470 ms and prevailed until 600 ms after word onset. In contrast to the N400 potential, the LPP was more pronounced over parietal leads. Effects are reported for single subjects` averaged activities from 470 ms - 600 ms including a group of 10 electrodes (CPz, CP3, CP4, Pz, P1, P2, P5, P6, PO3, PO4) at which the LPP could be reliably detected.

For the N400 and the LPP no hemisphere laterality effects were analyzed. Instead, brain activation elicited at single electrodes was collapsed across electrodes in order to get a topographically stable estimate of the underlying brain activity. Averaged activities of electrodes were entered into separate statistical analysis for the N400 and the LPP.

Figure 2 displays a layout of the electrode array and the labelled electrodes which were grouped for statistical analysis.

Figure 2: *Layout of the electrode array. Coloured labels show electrodes that were grouped for the statistical analysis of the early posterior negativity potential (red), the N400 potential (green), and the LPP (blue).*



3. Statistical Data Analysis

3.1. Early visual ERP potentials (3 Hz condition and 1Hz condition)

Effects of early selective processing of emotional and neutral adjectives were statistically examined by repeated measurements of variance (ANOVA). ANOVA included the factors 'Valence' (unpleasant, pleasant and neutral adjectives), 'Repetition' (five blocks per stimulation rate), 'Duration' (333 ms word exposure and 1000 ms word exposure) and 'Hemisphere' (left posterior sensors vs. right posterior sensors) as repeated measures. Interaction effects including the factor 'Hemisphere' are reported for normalized data.

Follow up planned comparison tests were performed to test affective modulation patterns across all three word categories ('Valence'), stimulus repetitions ('Repetition'), stimulation conditions ('Duration') and 'Hemisphere'.

3.2. Late visual ERP potentials (1 Hz condition only)

A. N400 and LPP

Effects of selective processing of emotional and neutral adjectives were analyzed for the N400 and the LPP, separately. For both brain potentials statistical analysis was obtained from separate ANOVA analysis including the factors 'Valence' (unpleasant, pleasant and neutral adjectives) and 'Repetition' (five blocks of repeated word presentations) as repeated measures.

Significance levels of early and late brain potential effects are reported after adjustment for violations of the sphericity assumption using the Huynh-Feldt procedure.

3.3. Memory performance

Memory performance for correctly remembered adjectives was statistically tested by repeated measurement ANOVA containing the main factor 'Recall Performance' (unpleasant, pleasant, and neutral word categories). Behavioural analysis contained data from fourteen out of sixteen participants because two participants did not take part in the free recall test.

4. Results

4.1. Visually evoked potentials

4.1.1. Early brain potentials (3 Hz and 1 Hz condition)

A. Effects of stimulus valence on early visual event-related potentials

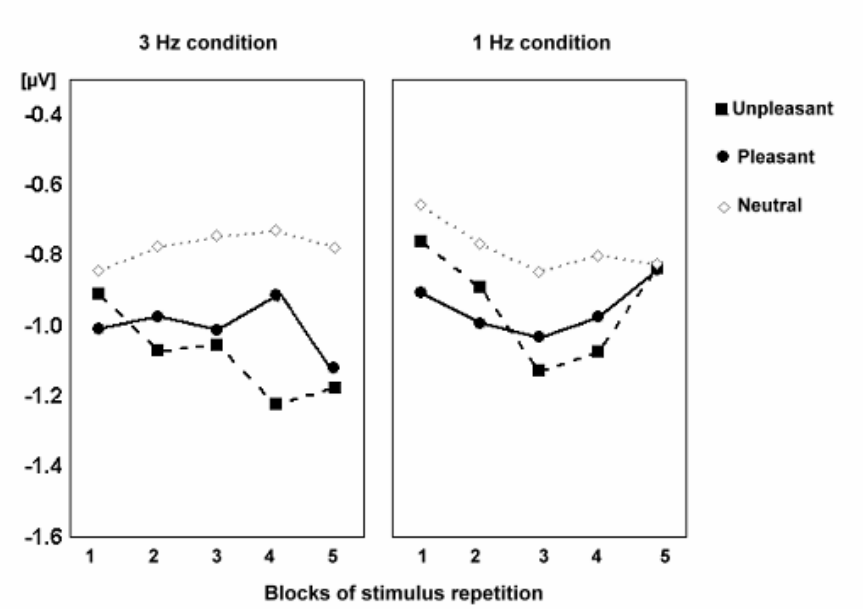
Early selective processing of emotional adjectives elicited 200 - 280 ms after word presentation was indicated by significant main effects of 'Valence' ($F(2,30) = 16.0$, $p < .001$). Post hoc tests revealed significantly increased amplitudes for unpleasant and pleasant adjectives compared to neutral adjectives ($F(1,15) = 23.5$, $p < .001$ for unpleasant > neutral and $F(1,15) = 23.9$, $p < .001$ for pleasant > neutral).

B. Effects of stimulus repetition on early visual event-related potentials

Across ten repetitions (five per stimulation rate) repeated stimuli did not attenuate the amplitude of the early posterior negativity potential significantly ('Repetition' $F(4,60) = 1.76$, $p > .15$).

There was no evidence for habituation of the emotion effect ('Repetition x Valence', $F(8,120) = 1.3$, $p_{Huynh\text{-}Feldt} > .25$ (Huynh-Feldt epsilon = 0.83)).

Figure 3a: *Effects of stimulus repetition on the affective valence pattern of the early posterior negativity. Left panel: 3 Hz condition. Right panel: 1 Hz condition. The x-axis represents the blocks of stimulus repetition (five per stimulation rate).*



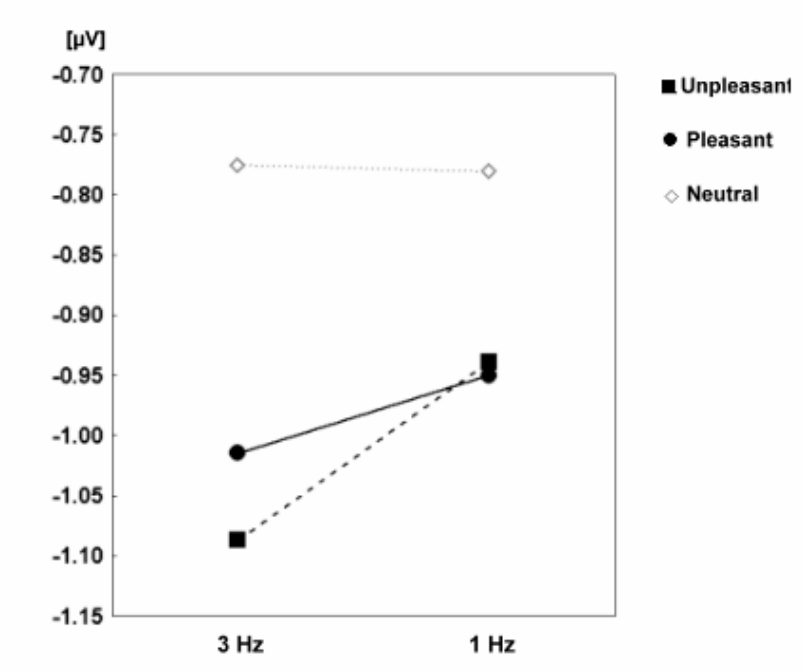
Across ten stimulation blocks (333 ms and 1000 ms word duration) the amplitude of the early negative potential reliably distinguished repeatedly presented unpleasant and pleasant adjectives from repeatedly presented, neutral adjectives irrespective of whether words were presented for 333 ms or 1000 ms ('Repetition x Duration x Valence': $F(8,120) = 0.8$, $p_{Huynh\text{-}Feldt} > .54$ (Huynh-Feldt epsilon = 1.0)). Effects are displayed in Figure 3a.

C. Effects of stimulus duration on early visual event-related potentials

No significant amplitude differences were found between adjectives presented at SOAs of 333 ms and 1000 ms ('Duration': $F(1,15) = .23$, $p > .64$).

However, affective processing tended to be more pronounced during the faster (333 ms) word presentations than during the slower (1000 ms) word presentations ('Duration x Valence': $F(2,30) = 3.2$, $p_{Huynh\text{-}Feldt} = .059$ (Huynh-Feldt epsilon = 1.0)). Particularly, unpleasant adjectives benefited from faster stimulus presentations (3 Hz > 1 Hz: $F(1,15) = 5.2$, $p < .05$; for unpleasant > neutral adjectives and 3 Hz: unpleasant > pleasant $F(1,15) = 3.6$, $p = .07$). Effects are displayed in Figure 3b.

Figure 3b: *Effects of stimulus duration on the affective valence pattern of the early posterior negativity. Left: 3 Hz condition. Right: 1 Hz condition.*



Grand average waveforms of the visual event-related potentials during viewing unpleasant, pleasant, and neutral adjectives are presented in Figure 4 for two representative occipital electrodes. Affective modulation of the averaged brain potential during 333 ms word presentation is presented in Figure 4a and during 1000 ms word presentations in Figure 4b. Topographic voltage maps of the difference potentials between emotional and neutral word categories (subtracting neutral from unpleasant, and neutral from pleasant adjectives) are also shown in Figure 4a (333 ms word duration) and Figure 4b (1000 ms word duration). Minimum norm plots giving an estimate of the brain electrical sources of the early affective modulation pattern are shown in Figure 4c.

Figure 4a: ***3 Hz condition***

Top: *Topographic maps of the difference potentials of the early posterior negativity potential, subtracting neutral from unpleasant and neutral from pleasant word categories.* ***Bottom:*** *Grand-averaged ERP waveforms during viewing of unpleasant, pleasant and neutral adjectives. Effects are shown for left and right occipital electrodes (O9 and O10).*

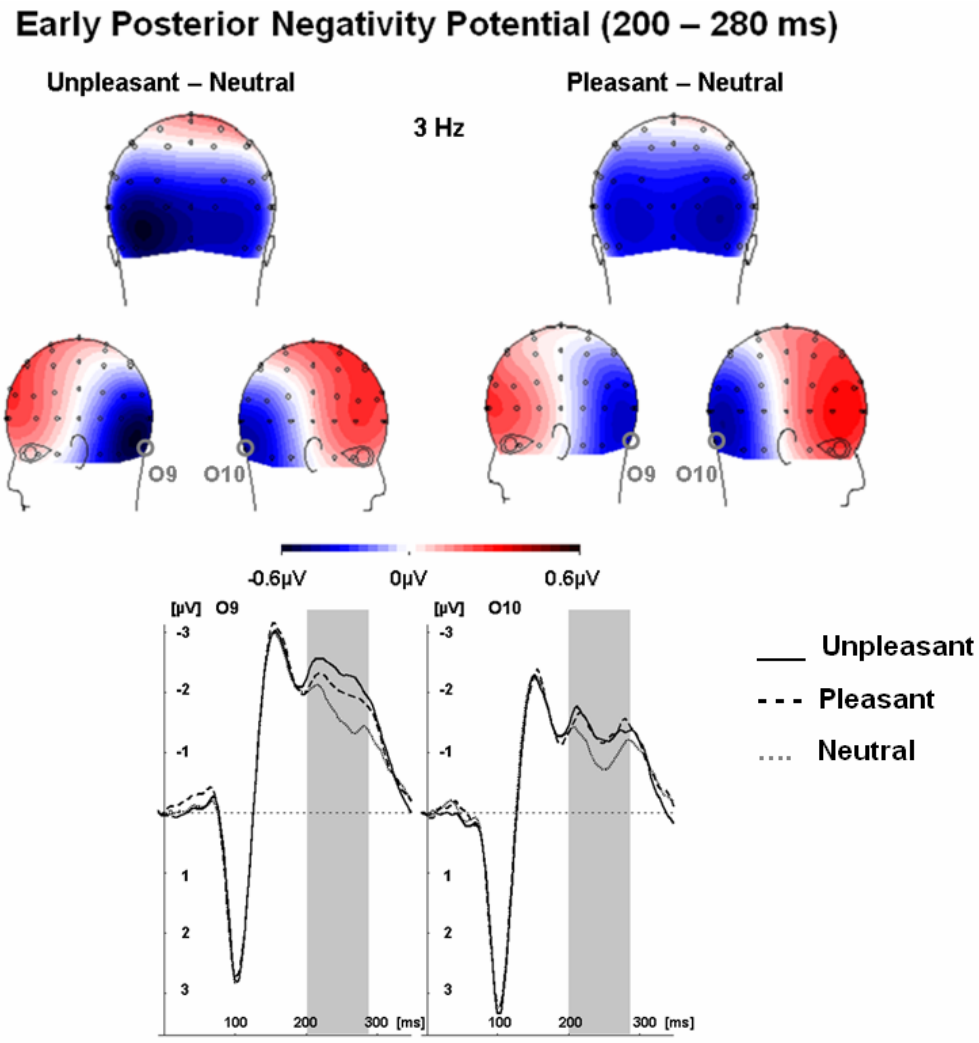


Figure 4b: ***1 Hz condition***

Top: *Topographic maps of the difference potentials of the early posterior negativity potential, subtracting neutral from unpleasant and neutral from pleasant word categories.* ***Bottom:*** *Grand-averaged ERP waveforms during viewing of unpleasant, pleasant and neutral adjectives. Effects are shown for left and right occipital electrodes (O9 and O10).*

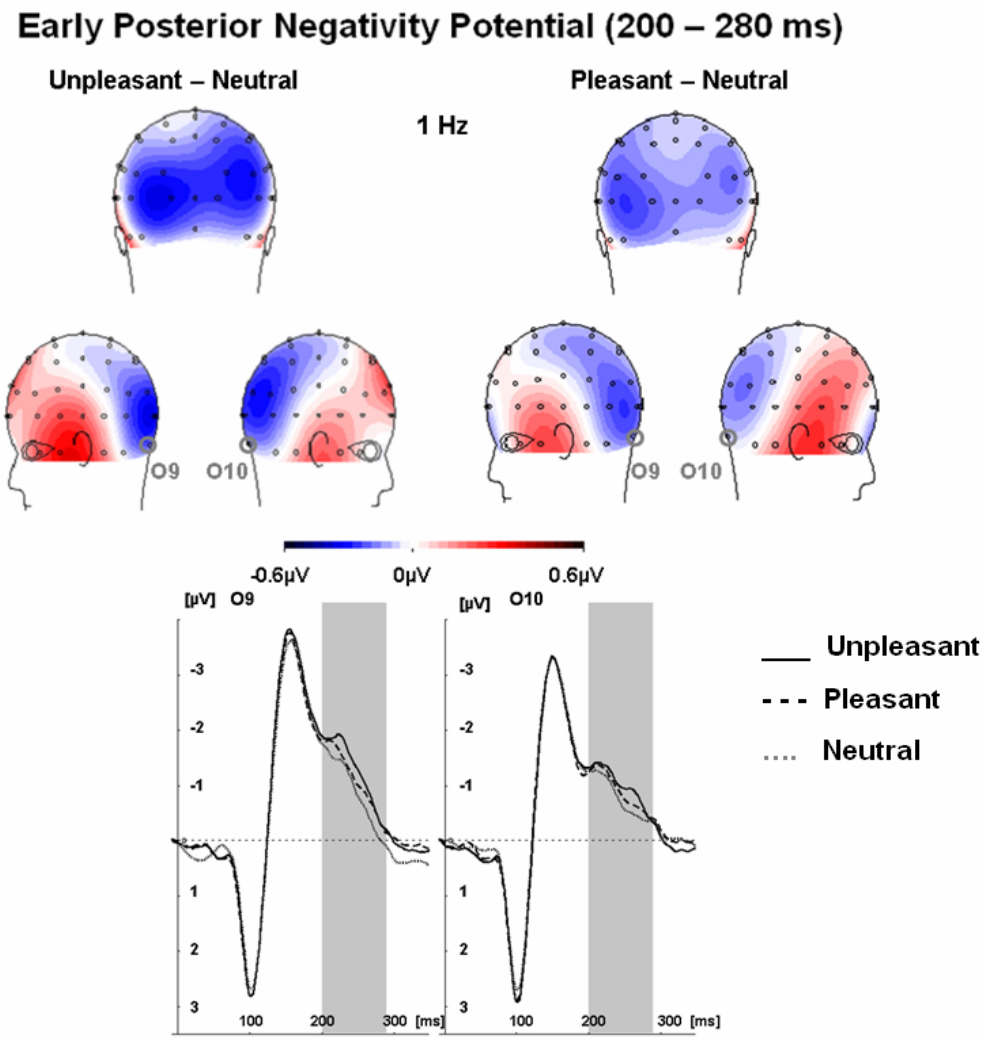
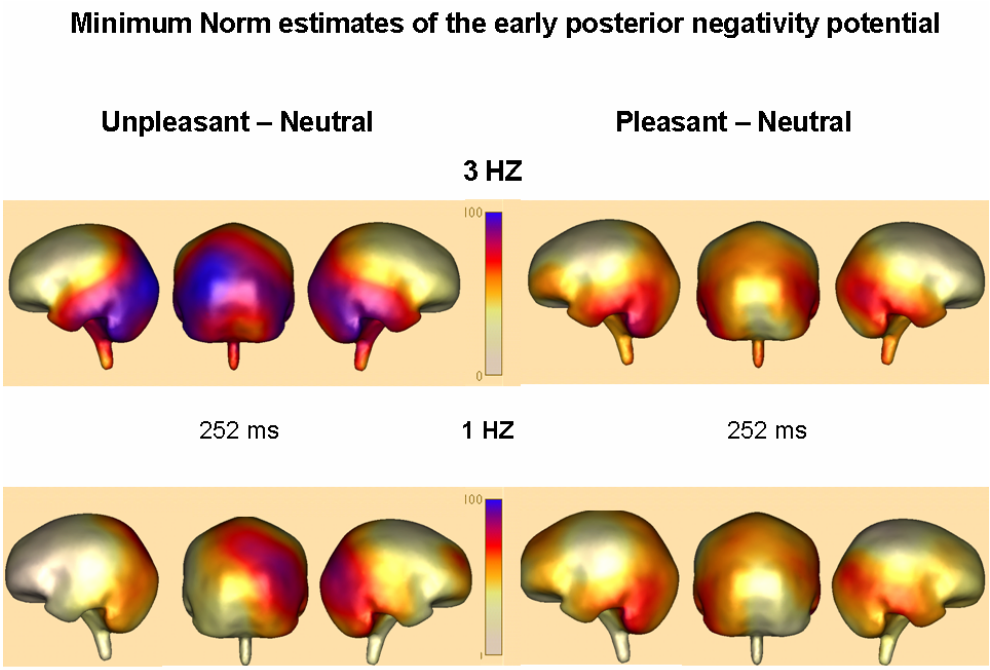


Figure 4c: *Figure 4c shows the cortical sources for the difference waves of the early posterior negativity potential, subtracting neutral from unpleasant and neutral from pleasant word categories.* ***Top:*** *3 Hz condition.* ***Bottom:*** *1 Hz condition. Minimum Norm Maps display the distribution for the respective maxima in global field power at 252 ms. Minimum Norm Maps were calculated according to the minimum norm algorithm of the BESA software package (MEGIS Software GmbH).*



D. Laterality Effects on early visual event-related potentials

Analysis of the topographic distribution of the early posterior negativity did not yield any significant effects for the main factor 'Hemisphere' ($F(1,15) = 1.16$, $p > .29$). Laterality effects varied as a function of the processing speed with respect to affective modulation ('Hemisphere x Duration x Valence': $F(2,30) = 4.6$, $p_{\text{Huynh-Feldt}} < .05$ (Huynh-Feldt epsilon = 1.0)). Post hoc tests revealed that the interaction effect was due to a stronger left-hemisphere dominant processing advantage for unpleasant compared to neutral adjectives at the shorter SOAs of 333 ms relative to the longer SOAs of 1000 ms word exposure (333 ms > 1000 ms: $F(1,15) = 5.9$, $p < .05$, for unpleasant > neutral adjectives). In contrast, no hemisphere dominant difference in affective processing across different processing speeds was obtained for pleasant adjectives compared to neutral adjectives (333 ms > 1000 ms: $F(1,15) = .55$, $p > .47$, for pleasant > neutral adjectives).

4.1.2. Late brain potentials (1 Hz condition only)

A. Effects of stimulus valence on the N400 and the LPP

When adjectives were presented for 1000 ms, they elicited a negative N400 brain potential starting at about 360 - 470 ms after word onset as well as a late positive brain potential (LPP) starting at about 470 - 600 ms after word onset. Both potentials had a definite regional focus over centro-parietal leads. Word content had a significant impact on both the N400 and the LPP amplitudes indicating better semantic processing (N400) and deeper encoding (LPP) of pleasant adjectives (N400: 'Valence' $F(2,30) = 3.2$, $p = .05$; LPP: 'Valence' $F(2,30) = 5.5$, $p < .01$). Post hoc test revealed smaller N400 amplitudes for pleasant compared to unpleasant adjectives (pleasant > neutral: $F(1,15) = 8.3$, $p < .01$) and larger LPP amplitudes for pleasant adjectives as compared to unpleasant and neutral adjectives (pleasant > neutral: $F(1,15) = 7.04$, $p < .01$; pleasant > unpleasant: $F(1,15) = 8.4$, $p < .01$). For unpleasant adjectives no valence effect was obtained (unpleasant > neutral: N400 and LPP all $p > .6$).

B. Effects of stimulus repetition on the N400 and the LPP

Word repetition had a significant impact on the N400 potential ('Repetition' $F(4,60) = 3.4$, $p < .05$). Across repeated word presentations the amplitudes of the N400 potential decreased significantly showing that word meaning was semantically integrated more easily at repeated occasion. By contrast, word repetition did not attenuate the amplitudes of the late positivity potential (LPP) significantly ('Repetition' $F(4,60) = .71$, $p > .58$). For both brain potentials the interaction between word repetition and word category (unpleasant, pleasant, and neutral) yielded no significant valence effects (N400: 'Repetition x Valence' $F(8,120) = .85$, $p_{Huynh\text{-}Feldt} > .56$ (Huynh-Feldt epsilon = 1.0); LPP: 'Repetition x Valence' $F(8,120) = .41$, $p_{Huynh\text{-}Feldt} > .9$ (Huynh-Feldt epsilon = 0.98)). Across word repetition valence effects were strongest for pleasant adjectives supporting the view that viewing pleasant words lead to better semantic and deeper encoding in contrast to viewing of any other word category during repeated presentations.

N400 and LPP affective modulation effects are presented in Figure 5. Grand average waveforms as well as topographic difference potential maps of the N400 component effects are shown in Figure 5a and in Figure 5b for the LPP component.

Figure 5: *N400 and LPP emotion effects (1 Hz condition only)*

Figure 5a: ***Right panel:*** *Topographic maps of the difference potential of the N400 potential, subtracting unpleasant from pleasant adjectives.* ***Bottom:*** *Grand-averaged ERP waveforms of the N400 potential during viewing of unpleasant, pleasant and neutral adjectives. Effects are shown for a representative centro-parietal electrode (CPz).*

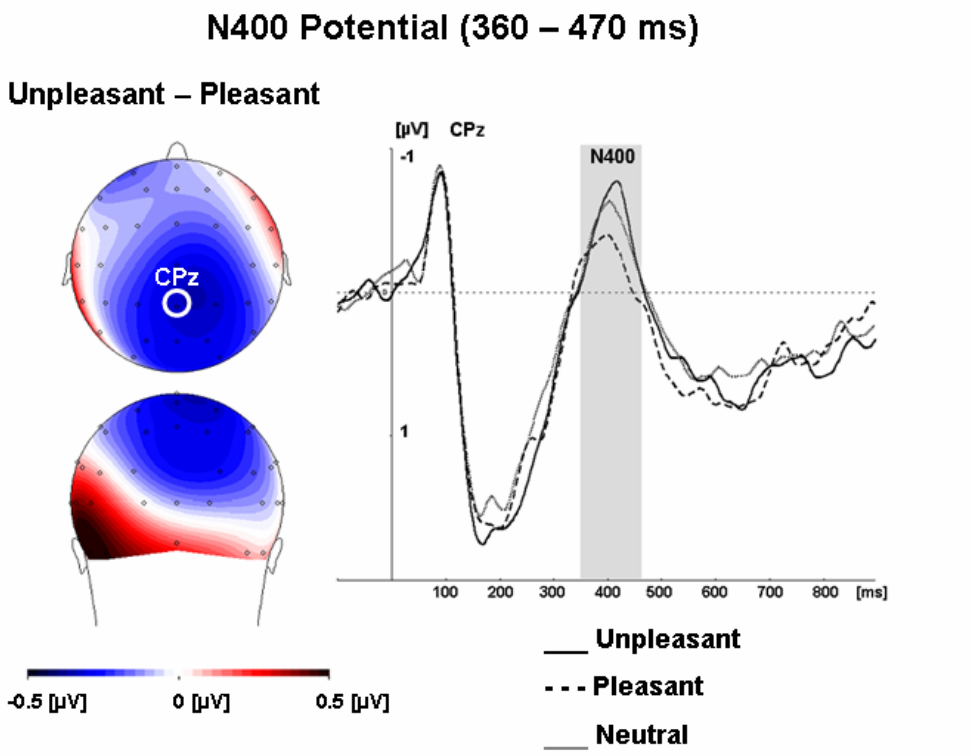
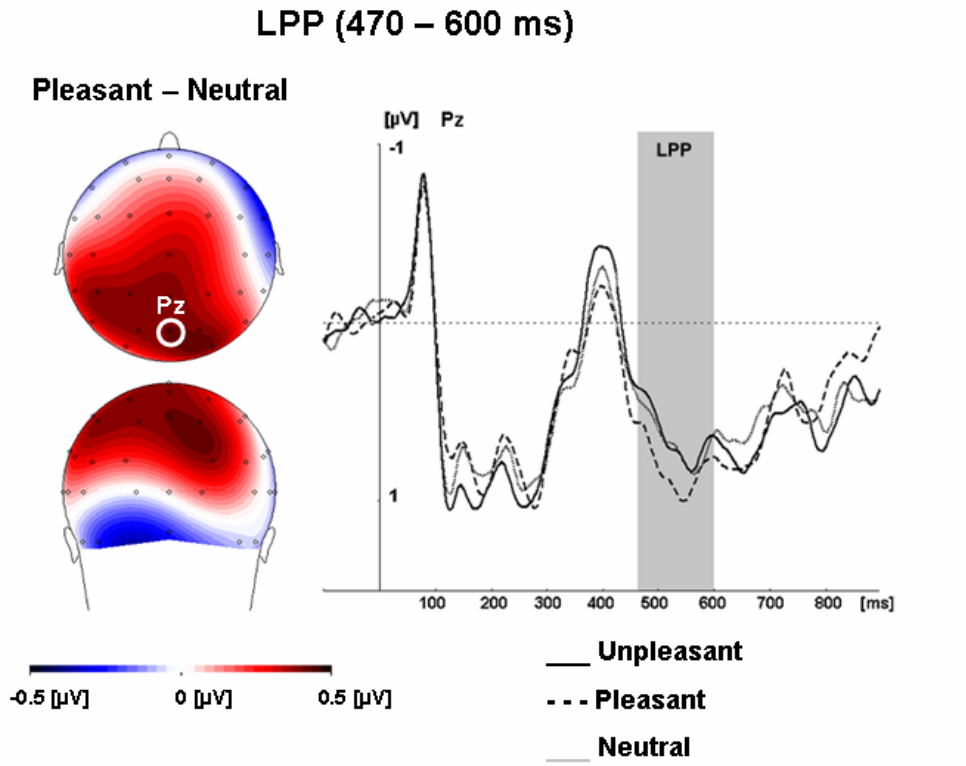


Figure 5b: ***Right panel:*** *Topographic maps of the difference potential of the LPP, subtracting pleasant from neutral adjectives.* ***Bottom:*** *Grand-averaged ERP waveforms of the LPP during viewing of unpleasant, pleasant and neutral adjectives. Effects are shown for a representative centro-parietal electrode (Pz).*



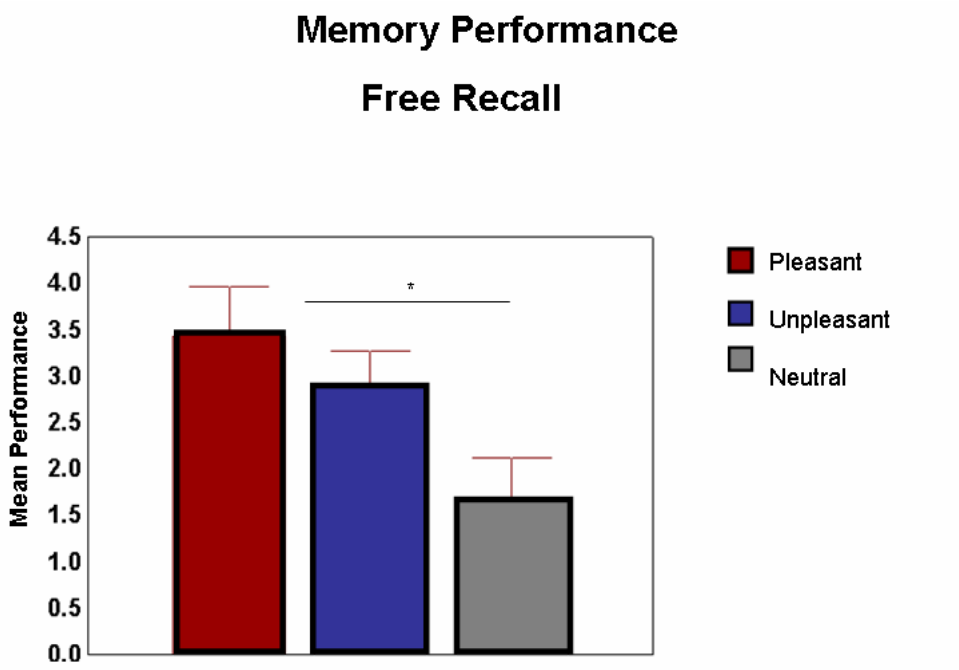
4.2. Memory performance

4.2.1. Behavioural data

As expected for free-recall tasks and RSVP designs retrieval of correctly remembered adjectives was rather small (Total amount of remembered words: M = 3.42). On the average only 3 items were correctly remembered. Nevertheless, emotional adjectives were remembered better than neutral ones as indicated by significant main effects of the factor 'Recall Performance' ($F(2,26) = 5.6$, $p < .01$). Only for pleasant items mean performance was associated with a more permanent memory trace (Total amount of correctly remembered pleasant words: M = 3.43, unpleasant words: M = 2.86, and neutral words M = 1.64). Post hoc tests revealed that better recall for pleasant compared to neutral words was significant ($F(1,13) = 11.08$, $p < .01$ for pleasant > neutral).

Memory performance of correctly remembered unpleasant, pleasant and neutral words is shown in Figure 6.

Figure 6: *Memory performance of correctly remembered unpleasant, pleasant and neutral words during a surprise free recall test at about 30 minutes after the end of the EEG experiment.*



5. Discussion

The current ERP study examined the time course of affective word processing in a passive viewing context. Words were presented in an RSVP design. Two different processing speeds (1 Hz and 3 Hz condition) were used to address early and late selection effects of emotional words. Emotional arousal and valence effects emerged. At early levels of word processing (200 – 280 ms) emotional arousal and unpleasant valence enhanced word perception. Early facilitation of emotional adjectives - in particular of unpleasant adjectives - was most pronounced at the faster processing speed (3 Hz) where words had to compete for limited attentional resources. At lower stimulus frequencies (1 Hz), unpleasant and pleasant words were equally able to capture attention at early levels of stimulus selection. Nevertheless, only pleasant words were selected for further sustained processing leading to better memory processing and recall. In the following, these emotion effects will be discussed, individually.

5.1. Effects of emotion on stimulus perception

Rapid serial visual presentation of emotional and neutral adjectives elicited an early negative brain potential distributed across bilateral temporo-occipital and parieto-occipital electrodes. For SOAs of both 333 ms and 1000 ms word duration, this early posterior negativity potential started at about 200 ms after word onset, was maximally pronounced after 250 - 260 ms and prevailed until 280 ms after word presentation. The topography and timing of the potential correspond with prior rapid RSVP research showing that meaningful words in contrast to meaningless stimuli elicit an early negative brain potential that has been termed 'recognition potential' ('RP') (Hinojosa et al., 2001, 2004; Martin-Loeches et al., 2001; Rudell, 1992). Selective processing differences between emotional and neutral adjectives were associated with significantly larger amplitudes of the negative potential indicating facilitated processing of highly arousing emotionally unpleasant and pleasant adjectives. Emotional adjectives in contrast to neutral adjectives were processed prioritized even when words were presented repeatedly. Across repeated blocks of word presentation amplitudes of the early negative potential reliably discriminated emotional from neutral adjectives (see Figure 3) confirming the view that emotion effects were not due to stimulus novelty (e.g., Schupp, Stockburger, Codispoti, Junghöfer, Weike et al., 2006b). Affective modulation of early posterior negative ERP components as described for the emotional words here have so far only been reported for rapidly presented highly arousing affective picture material depicting natural scenes with unpleasant and pleasant contents as well as for threatening faces (Junghöfer et al., 2001; Schupp et al., 2003a, b, 2004b, Schupp, Öhman, Junghöfer, Weike, Stockburger et al., 2004c). When pictures are presented briefly (e.g., in RSVP designs) a pronounced ERP difference occurs for emotionally arousing and neutral pictures that develops over occipito-temporal sensors and peaks at about 250 - 280 ms after picture presentation. The arising early posterior negativity has been termed 'EPN' component. Its modulation by the emotional picture content has been interpreted as an index of early selective affective processing. Extending emotion research on early processing of affective pictures our findings demonstrate that like affective pictures affective verbal connotations are processed instantaneously at early levels of perception. For emotional words as for affective pictures this impact of emotion on perception is indexed by an early posterior negativity potential that arises early in time at latencies reflecting early semantic stimulus processing (e.g., Martin-Loeches et al., 2001). As found for affective pictures (e.g., Junghöfer et al., 2001; Schupp et al., 2004b) early ERP modulation was most pronounced for highly arousing emotional (unpleasant as well as pleasant) adjectives. In line with the hypothesis, that emotional stimuli capture attention 'naturally' (e.g., Lang et al., 1997a), emotionally charged adjectives

were processed selectively and facilitated when words were viewed 'passively', that is, without prior instruction to attend to any specific word category. This 'stimulus-driven', 'natural' or 'motivated attention' of emotional words may be due to the amygdala enhancing perceptual vigilance for emotionally relevant verbal cues (Anderson et al., 2001). Using threat words and neutral words as target stimuli in an attentional blink paradigm Anderson and Phelps (2001) have shown that healthy participants are less likely to miss emotional targets than neutral targets. The attention enhancing effect of emotional words however was absent in amygdala damaged patients. Functional neuroimaging studies on affective word processing have reported increased neural activity in the amygdala as well as extrastriate and visual cortex areas during viewing highly arousing emotionally unpleasant (e.g., Isenberg et al., 1999; Strange, Henson, Friston, & Dolan, 2000; Tabert et al., 2001) words. It has been suggested that any visual input from higher order visual cortex regions is projected to the amygdala where it is evaluated for its emotional relevance (e.g., Amaral et al., 1992; see in LeDoux, 2001 and General Introduction on pp. 21 - 23 for an overview). Initial stimulus feedback from the amygdala to the visual cortex then in turn increases activity in brain areas associated with stimulus perception (primary and secondary cortex areas) and stimulus recognition (extrastriate visual cortex areas). As a consequence, attention to emotional stimuli will be increased reflexively and facilitate the processing of emotional stimuli (e.g., Anderson et al., 2001; Pessoa & Ungerleider, 2001). On a cortical level, this re-entrant processing between the amygdala and the visual cortex has been assumed to coincide with the affective modulation of early posterior negative brain potentials (e.g., Junghöfer et al., 2001). For lexical and pictorial stimuli brain responses as reflected by the early posterior negativity potential have been identified to originate from extrastriate visual cortex areas (e.g., Hinojosa et al., 2001, 2004; Martin-Loeches et al., 2001; Junghöfer et al., 2001). Thus, it may be that the significantly stronger posterior negativity pattern for emotional adjectives in contrast to neutral adjectives reflects an amygdala-driven process of facilitated recognition of emotional words in the visual cortex.

5.1.1. Influence of processing speed on emotional word perception

Processing speed had a significant impact on emotional word perception. At faster processing rates (333ms) emotional facilitation was most pronounced for unpleasant adjectives. In RSVP designs attention to subsequently incoming stimuli is limited. At SOAs of 200 – 500 ms stimuli have to compete for processing resources to be correctly identified (Raymond et al., 1992; Chun et al., 1995). Research has consistently shown that attention is drawn to negative information

more strongly and efficiently than it is to positive information (for emotional faces see Hansen & Hansen, 1988; Öhmann, Lundqvist, & Esteves, 2001c; for emotional pictures see Carretié et al., 2001; Smith, Cacioppo, Larsen, & Chartrand, 2003; Smith, Low, Bradley, & Lang, 2006; for emotional words see Pratto & John, 1991), especially at higher processing load where attention is limited (e.g., Anderson, 2005; Anderson et al., 2001; Smith et al., 2006). From an evolutionary point of view, a processing bias in favour of unpleasant information provides high survival value, specifically in conditions of limited attention, because it guarantees that no potentially dangerous or harmful stimulus will be missed (e.g., Öhmann et al., 2001a).

5.1.2. Laterality effects

Facilitated processing of affective adjectives did not yield any robust hemisphere dominant pattern. Affective modulation occurred over left and right posterior electrodes suggesting that early perceptual analysis of emotional words benefits from dual coding of words in both hemispheres. Stronger bilateral activation patterns at early stages of emotional processing have been related to stronger interhemispheric exchange processes (e.g., Compton, Feigenson, & Widick, 2005; Windmann, Daum, & Güntürkün, 2002). According to this view, emotional stimuli (e.g., faces and words) benefit from dual coding in both hemispheres to provide rapid discrimination of emotionally relevant stimuli from neutral stimuli (e.g., Windmann et al., 2002). However, emotional laterality effects may also depend on the processing speed with which words are presented. At faster stimulation rates, processing of unpleasant adjectives relative to neutral ones was more pronounced over the left hemisphere indicating a stronger contribution of the language-dominant hemisphere in the processing of temporal information (e.g., Nicholls, 1994, 1996) with aversive content.

5.2. Effects of emotion on postperceptual stimulus processing

The guidance of attention by emotional stimuli provides a means of enhancing emotional processing initially at early levels of stimulus perception. Moreover, it improves the availability of emotional information to other aspects of cognitive processing such as better semantic integration and deeper stimulus encoding. This has been shown repeatedly in EEG studies investigating early and late brain potentials elicited by highly arousing emotional stimuli such as pictures and words. In experimental designs favouring deep stimulus encoding (e.g., memorizing or evaluating words and pictures according to their semantic or emotional meaning) findings

confirm, that once appetitive or aversive stimuli are perceived, emotional arousal rather than stimulus valence determines the selection of emotional stimuli for further detailed processing with late positive potentials predicting enhanced stimulus encoding and better recall of both highly arousing pleasant and unpleasant pictures and words (e.g., Cuthbert et al, 2000; Dolcos et al., 2002; Fischler & Bradley, 2006; Fischler et al., unpublished; Palomba et al., 1997; Naumann et al., 1992; Schupp et al., 2000, 2004a). The impact of emotional arousal on later stimulus processing and memory however appears less robust and prone to decay in tasks that do not promote deep encoding strategies. When participants are not explicitly instructed to respond to semantic and emotional stimulus attributes no emotion effect on late ERP potentials has been found (Fischler et al., 2006; Leiphart et al., 1993; Naumann et al., 1996) or stronger effects of pleasant as opposed to unpleasant valence on late ERP potentials such as the P3/LPP and the N400 potential have been reported (e.g., Delplanque, et al., 2004; Kiefer et al., in press). Concerning pleasant valence, a processing bias in favour of pleasant verbal and nonverbal stimuli is also more consistently reported for behavioural measures and less complex tasks. When subjects have to categorize emotional and neutral pictures, faces and words according to simple physical stimulus attributes subjects respond faster to pleasant than to unpleasant and neutral stimuli (e.g., Ferré, 2003; Lehr, Bergum, & Standing, 1966; Leppänen & Hietanen, 2004; Leppänen, Tenhunen, & Hietanen, 2003; Kuchinke, Jacobs, Grubich, Vo, Conrad et al., 2005; Siegle, unpublished Master`s Thesis, http://www.pitt.edu/~gsiegle) and also remember more pleasant than unpleasant and neutral stimuli (e.g., Ferré, 2003; Kiefer et al., in press). The relatively stronger contribution of positively valenced relative to unpleasant stimuli has been explained in terms of individual pleasure preferences suggesting that healthy subjects prefer mood-congruent pleasant material in particular in settings were positive affect has been induced experimentally (e.g., Kiefer, et al., 2006) as well as in tasks that require no explicit emotional or semantic evaluation (see for an overview Ferré, 2003). Using a passive viewing context our analysis of late ERP potentials and memory data support a valence preference with respect to pleasant adjectives. When words were presented for 1000 ms, words elicited an early posterior negativity as well as an N400 potential and a late positive potential (LPP). Although perception was enhanced for unpleasant and pleasant adjectives the N400 potential and the LPP differentiated pleasant adjectives from unpleasant and neutral adjectives significantly indicating better semantic integration and deeper stimulus encoding for pleasant adjectives. Moreover, pleasant words were also better remembered.

5.2.1. Effects of pleasant words on late brain potentials (N400 and LPP) and memory

After a word has been presented meaning can be extracted very rapidly. This has been demonstrated for early posterior negativity potentials (e.g., 'RP' potential) as well as for the N400 potential (e.g., Hinojosa et al., 2001, 2004; Martin-Loeches et al., 2001; Rolke et al., 2001; Vogel et al., 1998). Whereas early posterior negativity potentials have been related to early semantic processing occurring as soon as a word is perceived, the N400 potential has been associated with post-lexical, semantic processing (e.g., Holcomb, 1993). Its amplitudes are assumed to reflect the ease with which semantic meaning can be integrated into the current context. The easier the integration, the smaller the N400 amplitudes and vice versa. Whereas early posterior negativity potentials are less affected by stimulus expectancy/probability (Rudell, 1991) and word repetition, the N400 is affected by both, stimulus expectancy and word repetition predicting better semantic integration for expected and repeatedly presented words (e.g., Rugg, Furda, & Lorist, 1988; Smith & Halgren, 1987). Word repetition had a significant impact on the N400 amplitude indicating better semantic integration of pleasant, unpleasant and neutral words over blocks of repeated word exposures. On the average, however, the N400 amplitude reduction was largest for pleasant adjectives in contrast to unpleasant adjectives implying that pleasant meaning could be integrated into the current context more easily than unpleasant adjectives. The differentiation between pleasant and unpleasant adjectives was most pronounced over centro-parietal electrodes starting from about 370 ms after word onset. The timing and distribution was very similar to that reported in N400-ERP studies using emotional or abstract words (see in Kutas et al., 2000; Schirmer, Kotz, & Friederici, 2005). Better semantic integration of pleasant as opposed to unpleasant words has been shown in recent ERP studies investigating mood-congruent processing effects. For instance, Schirmer et al. (2005) found faster lexical decisions and smaller N400 amplitudes to pleasant target words as opposed to unpleasant target words when pleasant words were primed by sentences spoken in happy intonations. Investigating subjects in optimistic and pessimistic mood, Chung et al. (1996) reported that mood-congruent words that predicted either a good or a bad ending of sentences elicit smaller N400 amplitudes than mood-incongruent words in a simple choice reaction time tasks (e.g., word-nonword distinctions). Pleasure modulation of the N400 amplitude has also been found when single words are presented randomly without an affective prime-target or sentence context: Kiefer and colleagues (in press), for instance, found that pleasant as opposed to unpleasant adjectives significantly attenuate N400 amplitudes in states of positive mood. Effects were most pronounced for degraded stimulus presentations. In all three studies mood-congruency effects extended to the time window of late positive potentials, indicating enhanced

amplitudes for mood-congruent pleasant words. In all three studies mood was induced experimentally either by presenting emotional sentences (Schirmer et al., 2005) or by showing emotional movies prior to word exposure (Kiefer et al., in press) or by asking subjects to adopt an optimistic or a pessimistic mood throughout the experiment (Chung et al., 1996). Given that mild positive affect characterizes the modal human experience in healthy subjects (e.g., Diener & Diener, 1996) our results imply a positive mood bias without establishing an explicit mood context other than that of reading words silently. Moreover, as indicated by the studies described above pleasant adjectives augmented amplitudes of late positivity potentials (LPP) supporting the notion that pleasant information attracts attention more efficiently and leads to deeper stimulus encoding than unpleasant and neutral information (Ferré, 2003; Kiefer et al., in press; Schirmer et al., 2005). In comparison to the N400 affective modulation pattern the LPP amplitude effect was statistically larger and not affected by word repetition. In contrast to the N400 potential the LPP differentiated pleasant from unpleasant and neutral adjectives. The affective differentiation started at the decline of the N400 potential at 470 - 600 ms after word onset and was most pronounced over centro-parietal and parietal electrode sites suggesting an involvement of 'attention' areas in the parietal cortex (e.g., Hopfinger, Buoncore, & Mangun, 2000). Pleasant adjectives differed in LPP amplitude measures and not in latency or topography from unpleasant and neutral adjectives supporting the notion that different levels of activation originate from the same rather than different neural sources (e.g., Allan, Wilding, & Rugg, 1998; Dolcos et al., 2002). Although stimulus repetition had no significant impact on the late positive potential, the cortical positivity for pleasant adjectives tended to increase with repeated word presentations. Behavioural studies have shown that stimuli increase in attractiveness with repeated exposure (e.g., Zajonc, 1968). This is especially the case when stimuli are presented passively without positive or negative reinforcement. The findings suggest that on the initial presentation, when stimuli are novel, both approach and avoidance tendencies get activated. When stimuli are repeated without having any negative or positive consequences for the individual, subjects learn quickly that the environment is safe and avoidance and escape tendencies are reduced, whereas approach tendencies increase (see Zajonc, 2001 for an overview). Thus, the passive nature of the task, together with the repeated exposure to the same words and the absence of negative reinforcement may have facilitated both the preference for pleasant adjectives and their consolidation in memory.

5.3. Effects of emotional content on free recall

For memory tested at a delay of 30 minutes overall performance was small. Nevertheless, pleasant adjectives were still remembered better than unpleasant and neutral ones. Superior recall for pleasant adjectives indicates that during encoding some pleasant information could be retained more than momentarily. Previous ERP studies have shown that late positive potentials are associated with better memory consolidation and recall (e.g., Dolcos et al., 2002; Palomba et al., 1997). The memory advantage for pleasant adjectives in contrast to unpleasant adjectives thus agrees with the stronger impact of pleasant adjectives on late positive potentials (LPP) during word presentation. It agrees also with demonstrations of better recall of pleasant events during shallow encoding conditions (e.g., Ferré, 2003; Kiefer et al., in press) as well as with findings reported for short memory retention intervals showing that a memory advantage for pleasant stimuli at immediate recall (e.g., minutes, days) is accompanied with larger cortical positivities to pleasant in contrast to unpleasant stimuli during encoding (e.g., Palomba et al., 1997). In RSVP designs competition from subsequent items leads to forgetting of most of the items. Meaning can be extracted rapidly. However, only that part of information that holds attention will be represented in memory and will be retained more than momentarily (e.g., Potter, 2005 for review). Previous RSVP research has shown that emotional stimuli benefit from rapid extraction of meaning at early levels of perception due to a rapid capture of attention (e.g., Anderson, 2005; Anderson et al., 2001; Junghöfer et al., 2001; Keil et al., 2004). None of the studies reported whether emotional stimuli attracted attention during later time points nor whether emotional stimuli obtained priority in memory processing. Extending this body of research, our results demonstrate that emotional facilitation can be reliably examined within RSVP designs by analyzing early and late brain potentials and testing memory performance. Even when presented on the fly and no instruction to attend was given, emotional words obtained priority during early and late processing stages and were remembered better than neutral words. Emotional arousal and valence cooperated differently during early and late stages of stimulus processing suggesting that motivational states can change within milliseconds. At early perceptual processing stages, stimulus detection benefited from emotional arousal acting as an unspecific alerting system ensuring rapid orienting to potentially dangerous or attractive stimuli. For faster processing speeds negative valence facilitated perception to assure adaptive survival giving primacy to unpleasant verbal concepts. At a postperceptual level pleasant valence enhanced semantic processing and memory encoding implicating a processing bias for words that match with individual pleasure preferences.

6. Conclusion

The present results complement previous studies on affective processing in important ways. The results demonstrate that emotional facilitation is not restricted to *biologically prepared* stimuli such as pictures and faces but extends to symbolic verbal stimuli with *ontogenetically learned emotional significance*. EEG-ERP potentials provide a means of studying emotion effects of different types of stimulus material and provide insight in the time course of emotional meaning processing. Our ERP results show how emotional arousal and valence interact at different levels of processing while subjects passively attend to a stream of incoming words. At early levels of processing the results support the notion that emotional arousal exerts a powerful effect by enhancing perception of stimuli with unpleasant and pleasant significance. Akin to affective picture studies we found that this early processing advantage is reflected in an early negativity potential that is most pronounced over the visual cortex, and occurs at similar latencies as observed for affective picture stimuli. The potential was elicited when participants simply viewed rapidly presented emotional words strengthening the view that emotional stimuli capture attention spontaneously. In support of a negativity bias in emotion perception, unpleasant words captured attention more efficiently than pleasant ones at faster stimulation rates where attention is limited and stimuli have to compete for perceptual awareness. Interestingly, this detection superiority for unpleasant words was not associated with better recall for unpleasant words. Similarly, Palomba et al. (1997) reported early facilitation of unpleasant and pleasant pictures. However, early facilitation did not correlate with later memory performance. Only in the later time windows of the LPP, enhanced cortical activation elicited by pleasant and unpleasant pictures was associated with better memory recall. Previous RSVP studies have demonstrated that meaning of words and pictures can be extracted much faster than it is represented in memory. At an early level of perceptual processing, semantic processing may be coarse (e.g., Mogg & Bradley, 1998; Potter, 2005) and emotional information is lost when not followed by a more detailed analysis that proceeds *after* the emotional significance of a stimulus has been identified. Apart from perception, emotional facilitation must include other aspects of cognitive processing to ensure that emotional meaning is integrated in the current context and gets updated in memory. In the literature two brain potentials have been associated with contextual integration of meaning: The N400 potential and late positive potentials (LPP). Whereas the N400 potential reflects the ease with which meaning can be integrated in the current context, late positive components (LPP) signal the updating process of meaning in memory. To date, a multitude of emotion studies has reported affective modulation of late brain potentials such as the N400 and the LPP. Emotional arousal and valence effects have been

found. With respect to emotional valence some studies have reported stronger activation for pleasant pictures, happy faces or pleasant words than unpleasant or neutral ones. Concerning N400 effects studies using verbal material suggest better integration of mood-congruent pleasant words than for mood-incongruent unpleasant words (e.g., Chung et al., 1996; Kiefer et al., in press; Schirmer et al., 2005). Concerning late positive potentials, pleasant picture stimuli provoke larger P3 potentials than unpleasant pictures when tasks require no explicit emotional stimulus evaluation (Delplanque et al., 2004; Keil et al., 2002). Erotic pictures having the highest rated arousal intensities produce larger late positive potentials than arousing unpleasant pictures (Schupp et al., 2004a). In adults, happy faces compared to angry faces evoke larger P3 potentials (Kestenbaum & Nelson, 1992). Larger P3 and late positive potentials have also been observed for pleasant nouns in contrast to unpleasant and neutral nouns (e.g., Schapkin et al., 2000). Several variables such as the hedonic nature of the stimulus, its emotional intensity, task instructions, attentional demands as well as individual preferences may influence the mobilization of processing resources devoted to affective stimuli at later processing stages. Using a passive viewing task the current results emphasize findings of a stronger impact of pleasant information on cognitive processing as indexed by the N400 and the LPP suggesting that subjects sustained more engaged in the processing of repeatedly presented pleasant rather than unpleasant or neutral adjectives. In support of the view that deeper engagement during encoding reflects memory updating, pleasant words were also better remembered than unpleasant and neutral adjectives. The beneficial effect of positive emotions/ positive affect on cognitive processing and its practical implications has been reviewed in recent papers (e.g., Isen, 2001; Fredrickson & Branigan, 2005) implicating that pleasant emotions broaden the scope of attention, enhance problem-solving, decision making, memory and well-being. Given that emotional states can change within milliseconds, ERP studies provide a suitable means to study the temporal dynamics and the differential impact of emotion on perception and cognition.

Theoretically, two-stage competition models of attention (Chun et al., 1995) provide a framework helping to explain ERP emotion effects obtained at early and late processing stages. According to these models, emotion effects reflected in amplitude modulations of the early negativity potential may then be interpreted as reflecting prioritized processing of emotional meaning at the perceptual stage of competition for attention. Emotional meaning can be extracted soon at this level but may be lost. Emotional stimuli that hold attention at a postperceptual level have access to a capacity-limited second processing stage where stimuli become integrated in the current context and get represented in memory. This postperceptual integration may be indexed by the N400 and LPP component.

IV. Chapter 3

Study 3: Brain structures involved in the incidental processing of emotional words

1. Introduction

From all the sensory stimuli received from our environment we recognize only those that are important to us, and those will become the focus of our attention (William James, 1901). Emotional stimuli are of particular importance for an individual because of their intrinsic survival value demanding priority access to perception and attentional selection (e.g., Lang et al., 1997a; Öhmann et al., 2001a). Today, researchers propose that the recognition of an emotional stimulus includes a sequence of evaluation processes. On the on hand, some evaluation may occur preattentively to provide rapid stimulus detection as soon as an emotionally challenging event occurs (e.g., Öhman et al., 2001a). On the other hand, some evaluation processes require conscious stimulus perception and attention to allow a more flexible, conceptual stimulus analysis for the purpose of accurate discrimination of salient events from the mundane (e.g., Öhman et al., 2001a; Rolls, 2000). In either case the amygdala, an almond-shaped brain structure located in the brain's left and right mediotemporal lobes has been pinpointed to be a key structure involved in the facilitative processing of emotionally significant events. Two major pathways along which the amygdala modulates visual sensory input have been proposed (see also in the General Introduction on pp. 21 - 23): Firstly, a primarily subcortical thalamo-amygdala pathway and second, a cortico-limbic processing pathway including direct projections between the amygdala and the visual cortex. While the subcortical processing route seems to be preempted for the automatic detection of biologically prepared fear-relvant stimuli (e.g., Liddell, et al. 2005; Morris et al., 1999, 2001; Vuilleumier, Armony, Driver, & Dolan, 2003), the cortico-limbic processing pathway has been suggested to play a key role in alerting the organism toward a variety of emotionally meaningful stimuli. Pioneering work in primates revealed an intensive communication between the amygdala and visual cortex areas of the ventral visual processing stream (Amaral et al., 1992). The ventral visual processing stream plays a critical role in object recognition and is located in the infero-temporal and occipital lobes (Ungerleider et al., 1982, 1994). The amygdala not only receives highly processed visual information from 'higher order' visual cortex areas but also projects back to all levels of the extrastriate ventral visual processing stream including the secondary and primary visual cortex. The relevance of this pathway in early

selective processing of emotional stimuli has been confirmed by a remarkable set of human neuroimaging studies using a broad range of unpleasant and pleasant stimuli from the standardized IAPS-International Affective Picture System as well as angry and happy faces (e.g., Breiter et al., 1996). In contrast to neutral picture stimuli, highly arousing pleasant and unpleasant pictures increase activity in occipital and extended infero-temporal areas of the ventral visual processing stream (e.g., Bradley et al., 2003; Lang et al, 1998c; Junghöfer et al., 2006) and additionally activate the amygdala (e.g., Junghöfer et al., 2005; Lane et al., 1999; Liberzon, Phan, Decker, & Taylor, 2003; Keightley et al., 2003; Mourao-Miranda, Volchan, Moll, de Oliveira-Souza, Oliveira et al., 2003; Sabatinelli et al., 2005). Effects have been observed during passive viewing conditions (e.g., Junghöfer et al, 2005, 2006), during attentive picture viewing (e.g., Keightley et al., 2003) and in some studies where processing resources were limited due to performance of an attention demanding secondary task (e.g., Lane et al., 1999). The findings have been taken as evidence that the amygdala modulates early selective processing of stimuli with emotionally appetitive or avoiding connotations. By enhancing perception and guiding 'natural' selective attention the amygdala ensures that emotionally salient stimuli gain priority access to a more detailed conceptual processing (cf. Bradley, et al. 2003; Lane et al., 1999).

However, what about other potentially emotional stimuli besides faces and pictures? Does the amygdala also enhance the selective processing of highly symbolic emotional stimuli such as words? In contrast to pictorial material, the emotional meaning of words is descriptive, less concrete, entirely acquired by learning and conveyed on the basis of semantics, raising the question if thalamic and visual cortex input may be sufficient for the amygdala to evaluate a word's emotional connotation and facilitate its perception. Several authors assume that in contrast to pictorial material the emotional connotation of written words may be analyzed after their meaning has been subjected to higher-level semantic processing and conscious recollection (e.g., Cacioppo et al., 1993; Danion, Kauffman-Muller, & Grange, 1995; Vanderploeg, Brown, Marsh, 1987). In agreement with this notion, imaging studies have found enhanced processing of emotional words in inferior prefrontal and middle temporal brain regions as well as fronto-limbic brain structures (e.g., medial and orbito-frontal brain areas). These brain regions are known to be involved in the processing of semantic and emotional meaning (Beauregard, Chertkow, Bub, Murtha, Dixon et al., 1997; Cato et al., 2004; Crosson, Cato, Sadek, Gokcay, Bauer, et al., 2002; Crosson, Radonovich, Sadek, Gokcay, Bauer et al., 1999; Kuchinke et al., 2005). Based on observations in amygdala damaged patients, who are quite able to use words such as 'fear' correctly in conversation some researchers propose that the amygdala may not necessarily be

involved in appraising emotional value from language stimuli (e.g., Adolphs, Tranel, & Damasio, 1998; Anderson & Phelps, 1998).

In spite of the fact that the perception of emotional words - even when words symbolize threat or danger – may not allow an exclusively subcortical processing of words on the basis of crudely processed thalamic input (e.g., Gaillard, Del Cul, Naccache, Vinckier, Cohen et al., 2006a; Naccache et al., 2005; White, 1996) there is evidence that the amygdala responds to highly arousing emotional words, to verbal cues signaling fear and positive or negative reinforcement and moreover, facilitates the perception of emotional words via its direct backprojections to the visual cortex.

1.1. Amygdala activation by emotional words

Recent fMRI findings show that verbal cues signalling negative (‘lose’) and positive (‘win’) reinforcement induce strong motivational engagement by activating the amygdala (e.g., Zalla, Koechlin, Pietrini, Basso, Aquino et al., 2000). In a similar vein, Phelps and colleagues (2001) have found that verbal cues signaling fear lead to activation of the amygdala and elicit physiological fear-responses similar to those that are learned through classical shock conditioning. Associative processing of highly arousing unpleasant and pleasant words has also proven to enhance activation in the amygdala when healthy subjects covertly evaluated any thoughts or feelings visually presented unpleasant, pleasant and neutral words elicited (Hamann et al., 2002). Interestingly, highly arousing pleasant words additionally evoked responses in brain structures related to reward, such as the nucleus accumbens and nucleus caudatus, implicating strong motivational activation during the evaluation of words that prime pleasant affective associations. Theoretically, it has been hypothesized that emotional stimuli are capable of increasing physiological arousal and emotional reactions of approach and avoidance by activating the brain`s appetitive or avoidance system (e.g., Lang et al., 1997a). Empirical research with emotional picture stimuli has accumulated strong evidence for this hypothesis (see Lang et al., 1997a; Bradley et al., 2000 for an overview). The reported imaging results visualize this assumption with regard to highly arousing unpleasant and pleasant verbal material.

1.2. Effects of emotion on word perception

In the last few years, human brain mapping and ERP studies revealed that extrastriate cortex regions located in the ventral and lateral parts of the inferior temporal lobe respond selectively to

words (e.g., Cohen et al., 2000; Gaillard, Naccache, Pinel, Clemenceau, Volle et al., 2006b; Nobre et al., 1994; Petersen, Fox, Snyder, & Raichle, 1990). Neural activity in these visual brain regions is sensitive to a word`s lexical and semantic features (e.g., Gaillard et al., 2006b; Nobre et al., 1994), to the degree of attention elicited by the presented words (e.g., Nacchache, Blandin, & Dehaene, 2002), occurs within the first 200 – 300 ms after word presentation (e.g., Gaillard et al., 2006b; Martin-Loeches et al., 2001) and presumably reflects early semantic processing (e.g., Martin-Loeches et al., 2001; Nobre et al., 1994; Vandenberghe et al., 1996).

Lesion studies and imaging data imply that the amygdala facilitates the recognition of emotional words in the visual cortex. Most of these studies employed unpleasant and neutral words. Studies with amygdala-lesioned patients show that amygdala damage impairs enhanced perceptual awareness for aversive words in an attentional blink paradigm: Whereas healthy subjects are better at detecting a second target occurring in close proximity to a first target stimulus if it was an emotionally aversive word (e.g., rape, bastard), damage to the amygdala abolishes this effect (Anderson et al., 2001). The authors hypothesized that the amygdala modulates attentive processing of emotional words by enhancing activity in brain regions associated with word recognition. Imaging studies with healthy subjects corroborate this hypothesis reporting enhanced activity in the amygdala and the visual cortex during attentive processing of emotional words. Isenberg and colleagues (1999) found enhanced bilateral amygdala and left parahippocampal/lingual and fusiform gyrus activation for threat words in contrast to neutral words in a modified emotional stroop paradigm. Additionally, threatening words activated premotor regions (BA 6) in the left frontal cortex, indicating preparation for action in response to perceived threat. Using a shallow encoding (subjects had to decide whether the first letter of a noun had an enclosed space) and a deep encoding condition (semantic decision of whether nouns belong to a living or non-living category), Strange and colleagues (2000) reported increased activity in the left amygdala and the fusiform gyrus, bilaterally, as well as in the left prefrontal cortex for emotionally deviant unpleasant nouns in an oddball paradigm. Prefrontal cortex activation was strongest during semantic encoding. By contrast, activation in the amygdala and the fusiform gyrus occurred during both encoding conditions supporting the view that early perceptual processing of unpleasant nouns is independent from depth of processing. Yet another fMRI study convinces of amygdala engagement in facilitated perception of emotional unpleasant words. Tabert and colleagues (2001) found increased right amygdala activity for unpleasant words (nouns and adjectives) being correlated with increased BOLD responses in bilateral secondary and primary visual cortices (BA 17, 18, 19) during an emotional decision task. Subjects (females) had to respond to the most unpleasant or neutral words. Time course analysis

revealed sustained amygdala and visual cortex activation over blocks of unpleasant word presentations indicating enhanced perceptual vigilance to words with strong unpleasant connotations (e.g., cancer, kill, ugly, agony, hell, etc.).

These findings demonstrate impressively that the amygdala enhances selective processing of emotional words by its modulatory influence on word perception and attention in the visual cortex. The findings also suggest that input from successive stages of visual word processing in the ventral visual processing stream is sufficient for the amygdala to further emotional word recognition and word encoding. At present, results are constrained to the processing of unpleasant, highly aversive words. Of course, there are imaging studies that have employed unpleasant and pleasant words (e.g., Hamann et al., 2002). However, many of these studies were designed to examine effects of emotion on semantic and memory processing (e.g., Cato et al., 2004; Crosson et al., 1999, 2002; Maddock, Garret, & Buonocore, 2003).

Only a paucity of imaging studies using both unpleasant and pleasant words aimed to investigate emotion effects on word perception and attention and results appear less consistent than those reported in studies using aversive words only. Using a blocked stimulus design, both emotionally unpleasant and pleasant words enhanced activation in bilateral occipital cortices and the left inferior temporal lobe when emotional words were contrasted against baseline conditions of viewing plus signs (Beauregard et al., 1997). In contrast to viewing blocks of concrete and abstract but emotionally neutral words, emotional words additionally activated areas in the left orbito-frontal and medio-frontal cortex suggesting an impact of fronto-limbic structures in the evaluation of emotional words. In this positron emission tomography (PET) study male student subjects were explicitly instructed to simply view the words ‘without thinking too much’ about the presented items (cf. Beauregard et al., 1997; pp. 459). Prior to word viewing participants were warned about the upcoming word category by the presentation of a plus sign indicating whether a word (abstract, concrete or emotional) or a random letter string will be expected. Emotional categories were not analyzed for differential effects between unpleasant and pleasant words. One frequently used paradigm to explore effects of affective word recognition is the lexical decision tasks (LDT) (e.g., Siegle, 1996 for an overview). Using fMRI and LDT, two functional imaging studies investigated brain responses elicited by words with unpleasant, pleasant and neutral valence and pronounceable nonwords. One study investigated healthy student subjects of both sexes (Kuchinke et al., 2005) and one study has focused on between-group effects comparing depressed females against normal controls (Canli, Sivers, Thomason, Whitfield-Gabrieli, Gabrieli et al., 2004). Across studies reaction time data of healthy subjects indicated significantly faster discrimination of pleasant as opposed to unpleasant and neutral

words. In the fMRI, better discrimination of emotional compared to neutral words was associated with stronger increase in the amygdala for pleasant words in healthy subjects than in depressed females (Canli et al., 2004) and in a number of other limbic (e.g., orbito-frontal cortex, hippocampus) and cortical (e.g., inferior and superior prefrontal cortex, anterior and posterior cingulate cortex and middle temporal cortex) brain regions in the second study yielding enhanced semantic and memory encoding of pleasant in contrast to unpleasant words (Kuchinke et al., 2005). The time it takes to make a lexical decision is thought to be a measure of lexical and semantic access and the cognitive effort/resources expended on the task (e.g., Balota & Chumbley, 1984; Coltheart, Davelaar, Jonasson, & Besner, 1977). Thus, when LDT paradigms are used in imaging studies, brain activation patterns may reflect the interaction of several processes associated with lexical and semantic processing and decision making. Accordingly, the results of the affective LDT paradigm studies described above suggest that these processes are enhanced for emotional, particularly pleasant words, in contrast to unpleasant and neutral words and associated with enhanced activation in cortico-limbic structures.

1.3. Effects of task demands on emotional processing

So far, the majority of imaging studies have all employed active tasks in which subjects were explicitly asked to attend to the words or categorize them according to emotional, lexical or semantic aspects. Whereas attention can have additive effects on emotional perception (e.g., Lane et al., 1997a; Isenberg et al, 1999; Pessoa et al., 2002a), cognitively demanding tasks can decrease stimulus-driven processing effects due to controlled processing (e.g., Hariri, Bookheimer, & Mazziotta, 2000; Ochsner, Bunge, Gross, & Gabrieli, 2002). Reviewing the literature in a recent meta-analysis, Phan and colleagues (2002) found that reports of amygdala activation are less consistent across studies that employed a cognitive task during emotion processing. Instead, 70% of the reviewed imaging studies that employed active task conditions showed activation in medio-frontal cortex regions. Emotion models propose that emotion processing may rely on at least two distinct systems. An implicit processing system that responds relatively automatically to environmental stimuli and on the other hand, an explicit processing system that operates mainly on the basis of consciously controlled emotional appraisal (e.g., Cunningham, Johnson, Gatenby, Gore, & Banaji, 2003; Elliot et al., 2000; Lane et al., 1997a). While activation of medio-frontal brain regions has been associated with controlled emotion processing, the amygdala appears to be more strongly engaged during implicit processing than during explicit, cognitively controlled processing of emotional stimuli (e.g., Cunningham et al.,

2003; Cunningham, Raye, & Johnson, 2004; Liberzon, Taylor, Fig, Decker, Koeppe et al., 2000). Concerning the more implicit type of emotion processing, no fMRI study has yet investigated emotional word processing during passive viewing conditions without any instructions other than to silently read the words.

In healthy adult native speakers, word reading is a highly overlearned automated skill. Normally, we read words without being told to do so, because words grab our attention, automatically (e.g., LaBerge & Samuels, 1974; Logan, 1988). Word reading consumes little cognitive capacity releasing cognitive capacity for understanding what is read. Thus, a passive viewing context of silent word reading seems to be an adequate task to study facilitation of emotional words, occuring spontaneously or implicitly as soon as a word is perceived and grabs attention.

1.4. Effects of emotional arousal

Another interpretational problem of previous studies concerns the control of stimuli for emotional arousal. In previous imaging studies it has often not been clear how valence and arousal may interact (e.g., Zald, 2003). However, especially emotional stimuli inducing high levels of arousal are assumed to benefit from a primarily amygdala mediated stimulus recognition and evaluation process (e.g., Glascher & Adolphs, 2003; Hamann et al., 2002; Kensinger et al., 2004; LaBar et al., 1998; Phan et al., 2003, 2004; Williams, Phillips, Brammer, Skerret, Lagopoulos et al., 2001). Unpleasant stimuli are regarded to be on the average emotionally more intense than pleasant stimuli (Ito et al., 1998b). Thus, differential responses between pleasant and unpleasant stimuli may be attributable to differences in emotional arousal in designs where emotionally pleasant and unpleasant stimuli are not controlled for emotional arousal. Stronger and different brain activation patterns for unpleasant than pleasant stimuli, for instance, could be attributable to the greater average intensity of unpleasant as opposed to pleasant stimuli. When words are matched for perceived arousal processing differences between pleasant and unpleasant stimuli can be compared more precisely. Concerning stimulus valence, differential effects of unpleasant and pleasant stimuli have been reported as showing either stronger amygdala responses to unpleasant stimuli than to pleasant ones (e.g., Breiter et al., 1996; Morris et al., 1998a) or stronger amygdala activation to pleasant compared to unpleasant pictures, faces, or words (e.g., Canli et al., 2004; Canli, Zhao, Desmond, Kang, Gross et al., 2001; Canli, Sivers, Whitfield, Gotlib, & Gabrieli, 2002).

1.5. Individual differences in emotion processing

Emotional processing depends on many aspects including effects of emotional arousal, task demands and participants` intentions, affective and motivational states. Regarding subjective factors, individual differences account for fundamental differences in responsiveness to either unpleasant or pleasant stimuli. People with mood disorders (e.g., anxiety, depression) and high-levels of negative affect show a processing bias toward unpleasant material that is associated with enhanced perceptual vigilance and enhanced neural responses in the amygdala (e.g., Abercrombie, Schaefer, Larson, Oakes, Lindgren et al., Davis & Whalen, 2001 for review; Sabatinelli et al., 2005). By contrast, there is reason from imaging data to assume that the opposite activation pattern may hold for healthy subjects (e.g., Canli et al., 2001, 2002, 2004) who are characterized by positive affect and a stronger preference for pleasant than unpleasant stimuli.

Extending findings from active to passive viewing conditions, the current fMRI study aimed to elucidate whether the processing of highly arousing unpleasant and pleasant words compared to low arousing neutral words initially enhances attention and perceptual word processing by activating the amygdala. To explore whether pleasant and unpleasant words elicit differential neural responses at similar levels of emotional arousal, words from the two emotional categories were carefully matched for perceived emotional arousal. Methodologically, event-related fMRI was used to study brain activity patterns attributable to differences in initial word recognition between emotional and neutral words. In contrast to blocked stimulus designs indicating tonic changes in hemodynamic brain responses, event-related designs have proven sensitive to detect subtle changes in brain activation associated with stimulus-locked, perceptual processing (e.g., Henson, 2003; Kleinschmidt et al., 1998). To examine whether passive viewing of emotional words had long-term effects on information processing, memory performance was tested by a surprise free recall task, 50 minutes after scanning.

2. Methods

2.1. Participants

Fifteen healthy, right-handed native speakers of German (8 males, 7 females; mean age: 26 years) without history of drug abuse, chronic bodily or neurological and psychiatric diseases or medication for any of these participated in the fMRI experiment. All subjects showed low levels of trait and state anxiety and low depression scores as indicated by the State-Trait Anxiety

Personality Questionnaire (Laux, Glanzmann, Schaffner, & Spielberger, 1981) as well as the Beck Depression Inventory (Hautzinger, Bailer, Worall, & Keller, 1994). All subjects had normal or corrected to normal vision. Handedness was determined using the Edinburgh Handedness Inventory (Oldfield, 1971). After being informed about potential risks associated with scanning participants gave written informed consent approved by the Neurological Department of the University of Tübingen Institutional Review Boards. Participant were payed a financial bonus of 15 Euros in return for participation.

Table 1: *Mean trait and state anxiety scores and BDI depression scores. Standard deviations are in parentheses. Data was acquired after scanning.*

Mean	Subjects (n = 15)
Trait Anxiety	32.7 (6.1)
State Anxiety	34.4 (7.1)
BDI Depression	4.7 (3.6)

2.2. Stimulus Material

The experimental stimuli comprised 102 adjectives. Adjectives were taken from a pool of about 500 German adjectives previously rated by 45 student subjects of the University of Konstanz. Ratings were obtained on the dimensions of perceived arousal and valence using the Self-Assessment Manikin scale (e.g., Lang, 1980; Lang et al., 1997b). Pleasant and unpleasant adjectives described a broad range of affective traits and states (e.g., successful, happy, in love, chilling, brutal, tortured, anxious, nervous, sick, etc.) whereas neutral adjectives described traits and states rated as less arousing and salient (e.g., neutral, normal, civilian, formal, etc.). Unpleasant and pleasant adjectives as well as neutral adjectives differed significantly in mean valence ratings ($F(2,99) = 391.3$, $p < .001$). Pleasant and unpleasant adjectives did not differ significantly in mean arousal but differed significantly from the neutral adjectives on this dimension ($F(2,99) = 349.2$, $p < .001$). Table 2 shows mean valence and arousal ratings of the highly arousing and low arousing emotional adjectives, respectively. Additionally, word categories (unpleasant, pleasant and neutral) were controlled for word length ($F(2,99) = 3.7$, $p > .02$), word frequency and concreteness. Concreteness of words was controlled by ratings of 31 student subjects of the University of Konstanz who did not take part in the current study. The

three valence categories did not differ significantly ($F(2,99 = 3.0, p > .06$). Word frequency was controlled by using frequency counts of the normative CELEX database for written German words (Baayen et al., 1995). Table 3 - 5 shows mean word length, word frequency and mean concreteness values obtained for unpleasant, pleasant and neutral adjectives, respectively. As can be seen in Table 3, unpleasant and pleasant adjectives had lower frequency counts as opposed to neutral adjectives but unpleasant and pleasant adjectives did not differ significantly in word frequency. The higher frequency count for neutral adjectives was primarily due to seven neutral adjectives having extremely high word frequency counts. When these outliers were excluded from statistical comparisons, unpleasant, pleasant and neutral adjectives did not differ in word frequency (word frequency: $F(2,99) = 8.3, p < .005$*; without outliers: $F(2,92) = 2.7, p > .07$).

Table 2: *SAM mean valence and arousal ratings of pleasant, neutral, and unpleasant adjectives rated by 45 students of the University of Konstanz.*

Mean Valence and Arousal Ratings	Adjectives		
	Pleasant	Neutral	Unpleasant
Valence	6.6 (.14)	5.2 (.09)	2.5 (.06)
Arousal	6.0 (.11)	3.0 (.06)	6.1 (.10)

The range and direction of the SAM ratings are as follows: pleasure = 9 (extremely pleasant) to 1 (extremely unpleasant), arousal = 9 (extremely arousing) to 1 (not at all arousing). Standard errors are in parentheses.

Table 3: *Frequency counts of written language (MannW) from the standardized word-database CELEX for pleasant, neutral, and unpleasant adjectives.*

Mean Word frequency	Adjectives		
MannW	Pleasant	Neutral	Unpleasant
without outliers	24.0 (6.2)	95.5 (25.6) 35.2 (7.1)*	16.0 (4.2)

Standard errors are in parentheses. *: Frequency counts after correcting for outliers.

Table 4: *Mean word length of pleasant, neutral, and unpleasant adjectives.*

Mean Word length	Adjectives		
	Pleasant	Neutral	Unpleasant
	8.9 (.46)	7.4 (.36)	8.4 (.34)

Standard errors are in parentheses.

Table 5: *Mean concreteness of pleasant, neutral, and unpleasant adjectives obtained from ratings of 31 student subjects of the University of Konstanz.*

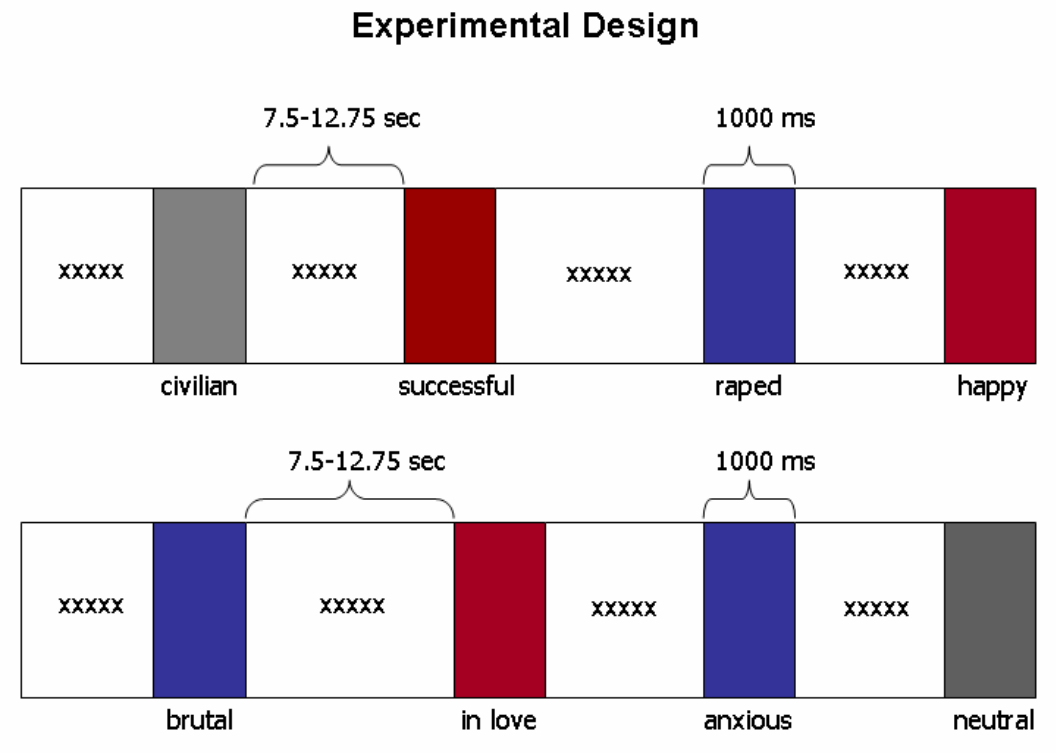
Mean Concreteness	Adjectives		
	Pleasant	Neutral	Unpleasant
	4.7 (.16)	4.6 (.29)	4.0 (.20)

The range and direction of the concreteness ratings are as follows: concreteness = 1 (extremley concrete) to 9 extremely abstract. Standard errors are in parentheses.

2.3. Experimental Design

Adjectives were divided into two sets of experimental stimuli, which were presented in two separate sessions of silent word reading. Each session contained 17 highly arousing pleasant, 17 highly arousing unpleasant and 17 low arousing neutral adjectives. In each session words were presented event-related, in fifty-one randomly assigned trials of unpleasant, pleasant and neutral adjectives. No word occurred twice to avoid habituation effects due to word repetition. Each word was presented for one second and was followed by a baseline trial, consisting of an array of letter strings matched with the mean word length of the adjectives. To improve signal-to-noise ratio, word onset was jittered relative to the scan onset, resulting in variable baseline intervals ranging from 7.5 seconds to 12.75 seconds. Figure 1 displays a schematic overview of the experimental design.

Figure 1: *Schematic overview of the experimental design.*



Stimulus presentation order was randomized across sessions and session order was counterbalanced over subjects. Experimental stimuli were presented parafoveally on a back-projection screen positioned in the scanner's head coil. Each session began with a baseline trial of random letter strings presented for 5 seconds to account for scanner drifts. Subjects were instructed to read each word silently.

Experimental runs were generated and controlled by 'Presentation' software (Neurobehavioral Systems Inc.).

Fifty minutes after scanning subjects were confronted with a surprise free recall memory test. Before scanning subjects were not informed about the subsequent memory test so as not to confound activations during silent word reading with cognitive processing related to memory rehearsal. Participants were asked to remember as many of the presented adjectives. In the free recall test adjectives had to be recalled along the three dimension of affective valence (unpleasant, pleasant and neutral words). An example of the free recall task can be found in the appendix section.

2.4. Physiological Data Collection and Reduction

2.4.1. Image acquisition

Functional and structural images were recorded on a 1.5 T-whole body scanner (Siemens Vision). Functional image acquisition was planned on a high resolution T1-weighted 3D-Turbo-Flash-Sequence anatomical reference scan. T1-weighted high-resolution (1 x 1 x 1,5 mm^3 voxel size) structural brain images were obtained for each subject using a rapid acquisition gradient echo (MPRAGE) sequence (192 slices, 0 mm gap, TR = 9,7 s, TE = 4 ms, $\alpha = 8$ °, FOV = 256 x 256 mm^2).

Functional images consisted of a whole-brain T2-weighted multislice echo-planar imaging (EPI) sequence. The multislice EPI sequence contained a volume of 28 parallel axial slices measured in descending direction (4-mm thickness, 1-mm gap, TR = 3 s, TE = 39 ms, $\alpha = 90$ °, FOV = 192 x 192 mm^2, 64 x 64 matrix).

2.4.2. Image analysis

Imaging data were analyzed using statistical parametric mapping software (SPM99, Wellcome Department of Cognitive Neurology, London, UK; http//: www.fil.ion.ucl.ac.uk/spm).

A. Preprocessing

The first five EPI images of each session were discarded from further analysis to exclude images susceptible to T1 saturation effects. Preprocessing of functional images included slice time correction using the mean image of the volume (image 14), 3D motion correction (realignment to the first image of the volume) and normalization to MNI space (Montreal Neurological Institute, Collins, Neelin, Peter, & Evans, 1994) using a standard EPI template (4 x 4 x 4 mm voxels). Data was spatially smoothed using an isotropic Gaussian Filter of 12 mm full width at half maximum (FWHM).

3. Statistical Data Analysis

Statistical analysis was based on the general linear model (GLM) (Friston, Holmes, Worsley, Poline, Frith et al., 1995). The evoked hemodynamic response (hrf) of each trial was modelled using the canonical hemodynamic response function (hrf) of the SPM99 software package. The hrf is based on empirical visual stimulation data consisting of two gamma functions (one

positive, one negative) shifted 2 seconds apart. All events were time locked to the onset of the verbal stimuli.

Analyses of group data were based on second-level random-effect analysis (Penny, Holmes, & Friston, 2003). For each contrast of interest, individual contrast images collapsed across the two sessions were analyzed and entered into a second-level group analysis with subject as the random-effect variable.

Five different T-contrasts were calculated:

A. Main effects of Lexicality (Words > Baseline)

Brain activity patterns elicited during reading words with emotional and neutral meaning were compared to their respective baseline conditions of letter viewing (xxxxxxxx) to control that participants had read and attended to all the presented words.

B. Main effects of Emotionality

B.1. Effects of emotional arousal (Emotion > Neutral)

To identify brain regions which respond to variations in emotional arousal, hemodynamic responses elicited during reading of high-arousal, unpleasant and pleasant adjectives were contrasted against low arousing neutral adjectives.

Unpleasant > Neural and Pleasant > Neutral

Brain activation patterns obtained for highly arousing emotional words were analyzed further by comparing unpleasant or pleasant words against neutral words.

B.2. Main effects of emotional valence: (Unpleasant > Pleasant, Pleasant > Unpleasant)

To delineate emotion effects related specifically to emotional valence, unpleasant and pleasant words were contrasted against each other.

Significant effects are reported for clusters of voxels extending a spatial threshold of 4 contiguous voxels at a significance threshold of $T > 2.98$, $p < .005$ (uncorrected). The statistical criterion of $p < .005$ (uncorrected) was selected on the basis of criteria used in other fMRI studies of affective word processing (e.g., Cato et al., 2004; Hamann et al., 2002).

For visualization of effects, statistical maps are overlaid on a representative high-resolution structural T1-weighted single subject image template from the MRIcro Software package (htpp//: www.mricro.com). The template is co-registered to the MNI image space (Montreal Neurological Institute; Collins et al., 1994). Anatomical localizations of effects were determined by using the TD Client software (Research Imaging Center, University of Texas Health Science Center at San Antonio). Therefore, signifcant voxel clusters of the SPM-MNI coordinates were approximated to Talairach coordinates using the 'mni2tal' formula, recommended by Mathew Brett (http://www.mrc-cbu.cam.ac.uk/Imaging/Common/mnispace.shtml).

C. Region of interest analysis (ROI)

Significant main effects of emotionality were specified further by regions of interest analysis (ROI) with special focus on the left amygdala. The ROI of the left amygdala was defined by an anatomical mask (Nielsen & Hansen, 2002). For ROI analysis, individual contrast images comparing each word viewing condition against the baseline condition were used (pleasant > baseline, unpleasant > baseline, and neutral > baseline). Activation was considered reliable for voxels extending a threshold of $p < .05$. The anatomical mask was coregistered (reslice only) and combined with the individual contrast images using the ImCal function of SPM99. Then, the mean signal change (mean beta-values) of voxels within the left amygdala were extracted from a sphere of 3 mm around the same peak voxel of the local maximum for each participant and valence category, respectively. Effects were tested by repeated measurement ANOVA.

3.2. Memory performance

3.2.1. Behavioural data

Free recall memory performance for correctly remembered 'old' words was statistically tested by repeated measurement ANOVA containing the main factor 'Valence' (unpleasant, pleasant, and neutral word categories). Memory performance of words that had not been presented, that is, words that were remembered erroneously as 'old' were analyzed by repeated measurements ANOVA containing the main factor 'Intrusions' (unpleasant, pleasant, and neutral word categories).

4. Results

4.1. Imaging Data

4.1.1. Main effects of Lexicality (Words > Baseline)

In agreement with the view that words grab attention automatically word reading in contrast to viewing meaningless letters (baseline) led to significant activations in brain areas relevant for lexical and semantic processing of words. In the visual system word recognition involved brain areas responsible for lexical and conceptual word analysis such as secondary visual areas (BA 18) and peristriate cortex regions in the middle occipital lobes (BA 18) as well as extrastriate cortex regions in the inferior occipital and temporal lobes (BA 37) in both hemispheres. Bilateral frontal effects were localized in the inferior prefrontal cortex (BA 9, BA 45, BA 47) including the left Boca's area. In temporal regions adjectives activated the left and right anterior and posterior parts of the middle and superior temporal gyrus (anterior: BA 38; posterior: BA 21, BA 22). The participation of these frontal and temporal brain regions indicates that words were semantically analyzed and comprehended. Additional activation was found in middle frontal regions including parts of the middle cingulate cortex (BA 32) and somatosensory and supplementary motor cortex, as well as in bilateral superior and in inferior parietal cortex regions (BA 7, BA 40). Cingulate cortex regions as well as inferior parietal cortex regions form part of the brain's fronto-parietal attention networks (e.g., Corbetta & Shulman, 1998, 1999, 2002; Peterson, Skudlarski, Gatenby, Zhang, Anderson et al., 1999; Posner & Petersen, 1990) indicating that subjects had attended to the words. Overall, the activation pattern corresponds well with imaging studies investigating effects of single word processing (e.g., Posner & Raichle, 1997 for an overview).

Figure 2 and Table 6 shows significant hemodynamic activation patterns obtained for unpleasant, pleasant, and neutral words as compared to baseline conditions of letter viewing.

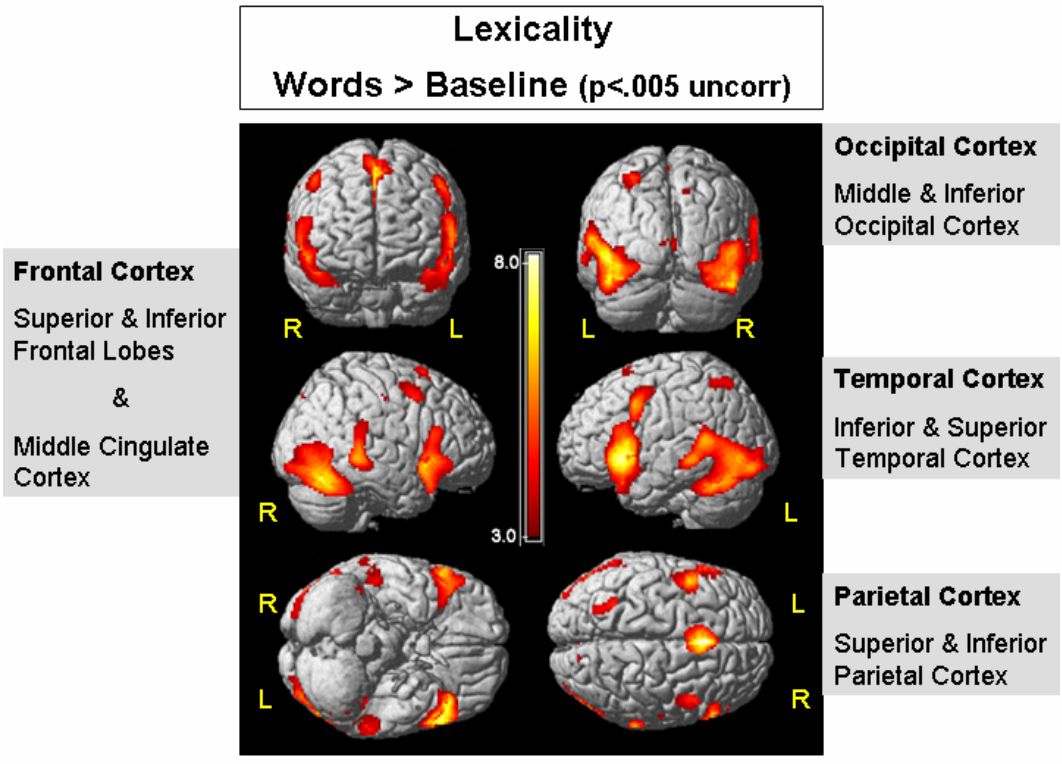
Table 6: *Significant T-values, MNI coordinates as well as respective Brodman areas (BA) of highest activated voxels within each brain region obtained for contrasts comparing activation during word reading (unpleasant, pleasant, and neutral adjectives) with activation during baseline conditions of letter viewing. SPM99, random-effects analysis, n = 15, p <.005 uncorrected, T > 2.98, k > 4.*

Words > Baseline

Hemi sphere	***Brain Region***	***Brodman (BA)***	***T – Value***	***Coordinates x, y, z MNI***	***Cluster***
Left	Occipital Lobe, Lingual	BA 18	4. 18	-4 -74 4	456
Left	Occipital Lobe, Lingual	BA 19	3. 39	-18 -64 -2	
Left	Inferior Occipital Gyrus	BA 19	8. 34	-48 -76 -4	3594
Left	Superior Parietal Lobe	BA 7	3. 85	-24 -66 58	183
Left	Inferior Parietal Lobe	BA 40	3. 78	-32 -54 56	
Left	Superior/Middle Temporal Gyrus	BA21/22	6. 50	-52 -46 6	
Left	Frontal Gyrus, Precentral	BA 4/6/9	6. 45	-40 8 38	
Left	Supplementary Motor	BA 8	7. 79	-4 18 54	1871
Left	Middle Cingulate Gyrus	BA 32	6. 39	0 20 40	
Left	Inferior Frontal Gyrus, Broca	BA 45	6. 04	-58 24 6	2988
Left	Inferior Frontal Gyrus	BA 47	7. 76	-42 22 -6	
Left	Cerebellum		6.65	-46 -68 -24	4
Right	Occipital Lobe, Lingual	BA 18	3. 26	24 -58 0	

Right	Inferior Occipital Gyrus	BA 19	5. 10	52	-76	0	
Right	Precentral/Postcentral Gyrus	BA 3/4	3. 31	60	-16	46	4
Right	Parietal Lobe, Precuneus	BA 7	3. 41	14	-82	46	
							7
Right	Inferior Parietal Lobe	BA 40	3. 25	68	-30	26	
Right	Superior Temporal Gyrus	BA 38	6. 67	48	20	-18	
							1333
Right	Superior Temporal Gyrus	BA 22	4. 08	66	-36	14	
Right	Middle Temporal Gyrus	BA 21	6. 38	60	-36	-2	733
Right	Inferior Temporal	BA 37	7. 67	50	-56	-22	2526
Right	Middle Frontal	BA 6	5. 15	48	6	54	
Right	Middle Frontal, Precentral	BA 6	3. 24	46	-4	58	
							167
Right	Inferior Frontal Gyrus	BA 47	5. 53	60	20	0	
Right	Inferior Frontal Gyrus	BA 47	5. 13	54	28	-10	
Right	Cerebellum		7. 42	46	-66	-22	4

Figure 2: *Significant effects for the main contrast comparing adjectives against baseline (red). For visualization of effects, functional brain activation maps (spmT-images) are superimposed on a single subject T1-weighted image from the SPM canonical image space displayed at a threshold of p <.005 (uncorrected), with a spatial extend threshold of 4 contiguous voxels.*



4.1.2. Main effects of Emotionality

A. Effects of emotional arousal (Emotion > Neutral)

Compared to less arousing neutral adjectives highly arousing emotional adjectives significantly augmented blood oxygen level dependent (BOLD) responses in limbic structures as well as in the left visual cortex and in bilateral posterior and prefrontal cortex areas. Limbic system activity included the left amygdala and the adjacent left parahippocampal regions. Activation in the left visual cortex comprised primary (BA 17, BA 18) and secondary visual association areas in the middle occipital cortex (BA 18, BA 19) as well as in the left infero-temporal, extrastriate cortex areas of the fusiform gyrus (BA 20). Additional activation in the middle superior frontal cortex (BA 9) included left and right premotor (BA 6) areas and middle cingulate cortex regions, as well as the left and right superior parietal lobes (BA 3, BA 5, BA 7) and the left and right cerebellum (see Figure 3).

Table 7 gives an overview of significant emotion effects obtained for contrast images comparing emotional adjectives against neutral adjectives.

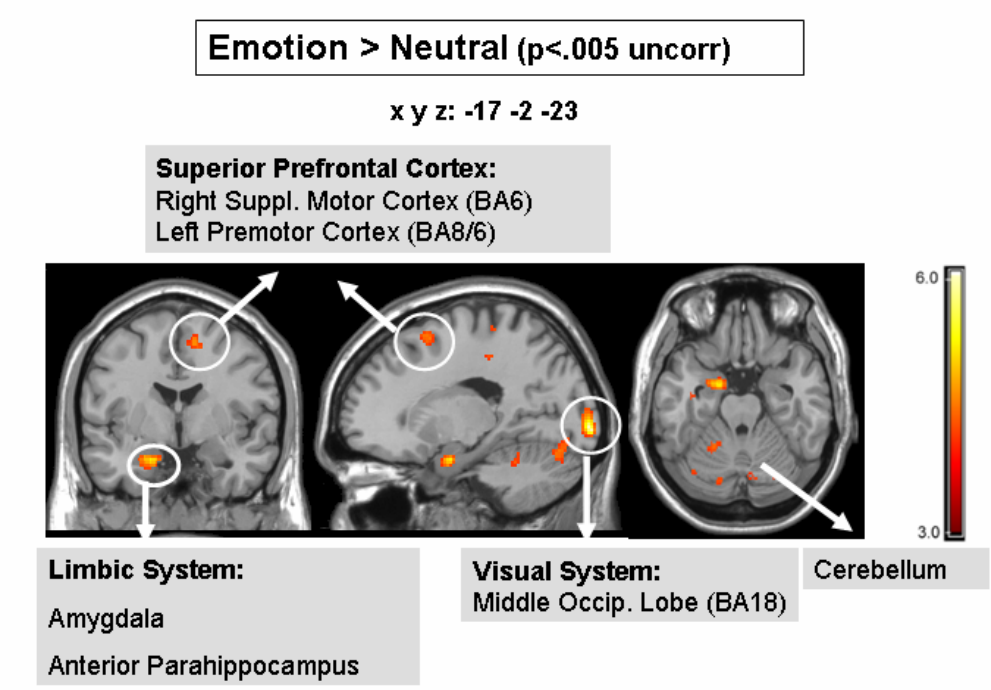
Table 7: *Significant T-values, MNI coordinates as well as respective Brodman areas (BA) of highest activated voxels within each brain region obtained for contrasts comparing activation during emotional word reading with activation during neutral word reading. SPM99, random-effects analysis, n = 15, p < .005 uncorrected, T >2.98, k >4.*

Emotion > Neutral

Hemi sphere	*Brain Region*	*Brodman (BA)*	*T – Value*	*Coordinates x, y, z MNI*	*Cluster*
Left	Occipital Lobe, Lingual	BA 17	6. 31	-14 -100 -4	295
Left	Occipital Lobe, Lingual	BA 18	3. 54	-14 -76 -20	
Left	Middle Occipital Gyrus	BA 19	5. 70	-20 -96 4	55
Left	Parietal Lobe, Postcentral	BA 3	3. 09	-18 -34 64	4
Left	Parietal Lobe, Precuneus	BA 5	3. 46	-8 -44 74	19
Left	Inferior Temporal Lobe, Fusiform Gyrus	BA 20	3.43	-36 -7 -26	5
Left	Temporal Lobe, Fusiform Gyrus	BA 20	3. 32	-38 -12 -26	11
Left	Superior/Medial Frontal Gyrus	BA 6	3. 47	-16 10 58	24
Left	Superior Frontal Gyrus	BA 9	3. 63	-10 54 36	23
Left	Middle Cingulate Gyrus	BA 31	3. 31	-6 -24 44	6
Left	Middle Cingulate Gyrus	BA 31	3. 32	-18 -30 46	12
Left	Limbic System: Anterior Parahippocampus		4. 60	-16 -4 -24	

					84
Left	Amygdala		3. 16	-18 -2 -18	
Left	Caudatus		3. 43	-24 -26 24	11
Left	Cerebellum		3. 80	4 -56 -16	
					28
Left	Cerebellum		3. 42	-18 -48 -26	
Right	Parietal Lobe, Precuneus	BA 5/7	4. 00	8 -50 72	22
Right	Supplementary Motor	BA 6	4. 20	12 -6 56	66
Right	Cerebellum		3. 29	12 -56 -18	
					142
Right	Cerebellum		3. 83	20 -82 -36	
Right	Cerebellum		3. 3	22 -76 -28	
					131
Right	Cerebellum		3. 21	12 -76 -34	
Right	Cerebellum		3. 23	4 -72 -18	12

Figure 3: *Significant emotion effects for emotional adjectives > neutral adjectives. For visualization of effects, functional brain activation maps (spmT-images) are superimposed on a single subject T1-weighted image from the MRIcro Software package displayed at a threshold of p <.005 (uncorrected), with a spatial extend threshold of 4 contiguous voxels. Coordinates (x, y, z) correspond to MNI image space.*



B. Emotion effects: Pleasant > Neural and Unpleasant > Neutral

Activity in the left middle occipital cortex and the superior frontal cortex was confirmed for both pleasant as well as unpleasant adjectives compared to neutral adjectives. However, especially highly arousing pleasant words elicited significant activation in the limbic system and the left inferior occipital and temporal cortex suggesting a stronger impact of pleasant valence on amygdala mediated word perception. The local maxima of significant voxels in the limbic cluster was located in the peri-amygdaloid complex comprising the left amygdala and the left anterior parahippocampus (pleasant > neutral: MNI: -14 0 -24; -22 0 -24). Unpleasant adjectives as opposed to neutral adjectives exhibited limbic activation when a less stringent significance criterion of p <.009 was used (see Figure 4 right panel). Akin to the pleasant > neutral contrast (T >2.9, p <.005), the cluster in the limbic system for the unpleasant > neutral contrast (T >2.7, p <.009) included the left amygdala and the left adjacent anterior parahippocampus.

As can be seen in Table 8 and Figure 4, pleasant words also lead to stronger increase in left middle cingulate (BA 23, BA 31) and parietal cortex regions including the left and right inferior parietal cortex (BA 40), indicating that subjects attended to pleasant words more strongly than to any other word category.

Table 8: *Significant T-values, MNI coordinates as well as respective Brodman areas (BA) of highest activated voxels within each brain region obtained for contrasts comparing pleasant against neutral adjectives (**Table 8a**) and unpleasant against neutral adjectives (**Table 8b**), respectively. SPM99, random-effects analysis, n = 15, p < .005 uncorrected, T >2.98, k >4.*

Table 8a: Pleasant > Neutral

Hemi sphere	***Brain Region***	***Brodman (BA)***	***T - Value***	***Coordinates x, y, z MNI***	***Cluster***
Left	Occipital Lobe, Calcarine	BA 17/18	6. 47	-14 -100 -6	405
Left	Middle Occipital Gyrus	BA 18	4. 99	-22 -96 10	
Left	Inferior Occipital Lobe, Fusiform Gyrus	BA 19	3. 77	-42 -68 -16	69
Left	Parietal Lobe, Postcentral	BA 4	3. 41	-18 -34 64	13
Left	Parietal Lobe, Precuneus	BA 5	3. 12	-8 -44 74	6
Left	Inferior Parietal Lobe	BA 40	3. 57	-40 -38 44	53
Left	Temporal Lobe, Fusiform Gyrus	BA 20	4. 14	-36 -8 -26	43
Left	Inferior Temporal Lobe, Fusiform Gyrus	BA 37	3. 30	-44 -58 -14	
Left	Superior Frontal Gyrus	BA 6	4. 23	-18 12 60	111
Left	Middle Frontal	BA 8/9	3. 11	-32 42 40	16
Left	Middle Cingulate	BA 23	3. 90	-6 -24 44	98

Left	Middle Cingulate	BA 31	3. 55	-18 -30 46	
Left	Limbic System:				
	Anterior Parahippocampus			-14 0 -24	
			5. 52		133
	Amygdala			-22 0 -24	
Left	N. Caudatus		3. 43	-24 -24 22	14
Left	Cerebellum		4. 39	-26 -54 -26	
Left	Cerebellum		3. 21	-36 -70 -26	
					184
Left	Cerebellum		3. 82	-34 -52 -30	
Right	Inferior Parietal Lobe	BA 40	3. 83	24 -46 46	64
Right	Inferior Temporal Gyrus	BA 20	3. 30	36 6 -48	7
Right	Medial Frontal Lobe	BA 9/48	3. 43	24 26 30	16
Right	Supplementary Motor Cortex	BA 6	3. 50	10 -4 54	7
Right	Cerebellum		4. 08	12 -74 -36	
Right	Cerebellum		3. 42	18 -76 -26	
					240
Right	Cerebellum		3. 65	24 -68 -28	
Right	Cerebellum		3. 62	14 -58 -20	17
Right	Mamillary Body		3. 94	8 -14 -14	36

Table 8b: Unpleasant > Neutral

Hemi sphere	*Brain Region*	*Brodman (BA)*	*T - Value*	*Coordinates x, y, z MNI*	*Cluster*
Left	Occipital Lobe, Cuneus	BA 18	3. 50	-20 -96 -4	40
Left	Middle Occipital Gyrus	BA 18	3. 38	-20 -96 6	
Left	Superior Frontal Gyrus	BA 9	3. 41	-10 56 36	12
Left	Limbic System: Parahippocampus, Amgdala		**2.76 p<.009**	-22 -4 -26	17
Left	Cerebellum		3. 15	0 -50 -20	4
Right	Supplementary Motor	BA 6	3. 68	14 -6 56	43
Right	Cerebellum		4. 20	22 -84 -34	80
Right	Cerebellum		3. 35	4 -54 -14	50

Figure 4: *Significant emotion effects for contrasts comparing pleasant adjectives > neutral adjectives and unpleasant adjectives > neutral adjectives. For visualization of effects, functional brain activation maps (spmT-images) are superimposed on a single subject T1-weighted image from the MRIcro Software package. In Figure 4b, limbic activation is displayed at a threshold of p < .005 (uncorrected) for pleasant contrasts and at a threshold of p < .009 (uncorrected) for unpleasant contrasts.*

Figure 4a: *Visual system activation comparing pleasant against neutral (left upper panel as well as bottom panel) and unpleasant against neutral adjectives (right upper panel).*

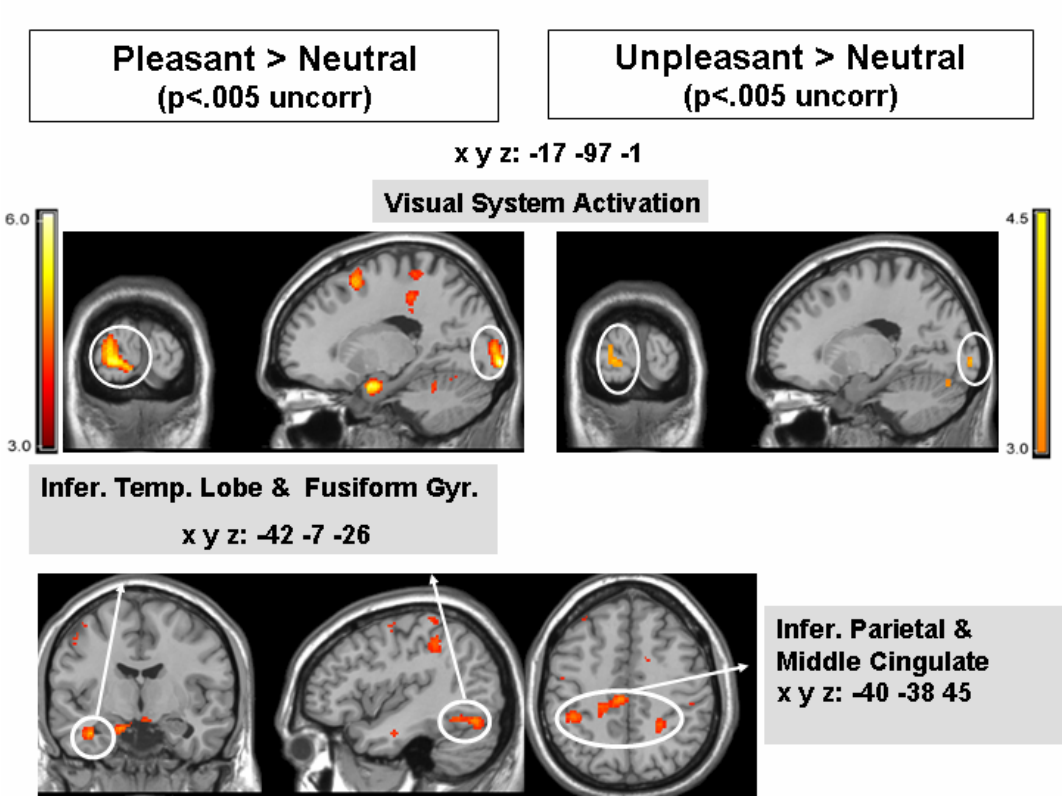


Figure 4b: *Limbic system activation comparing pleasant against neutral (left upper panel as well as left bottom panel) and unpleasant against neutral adjectives (right upper and bottom panel).*

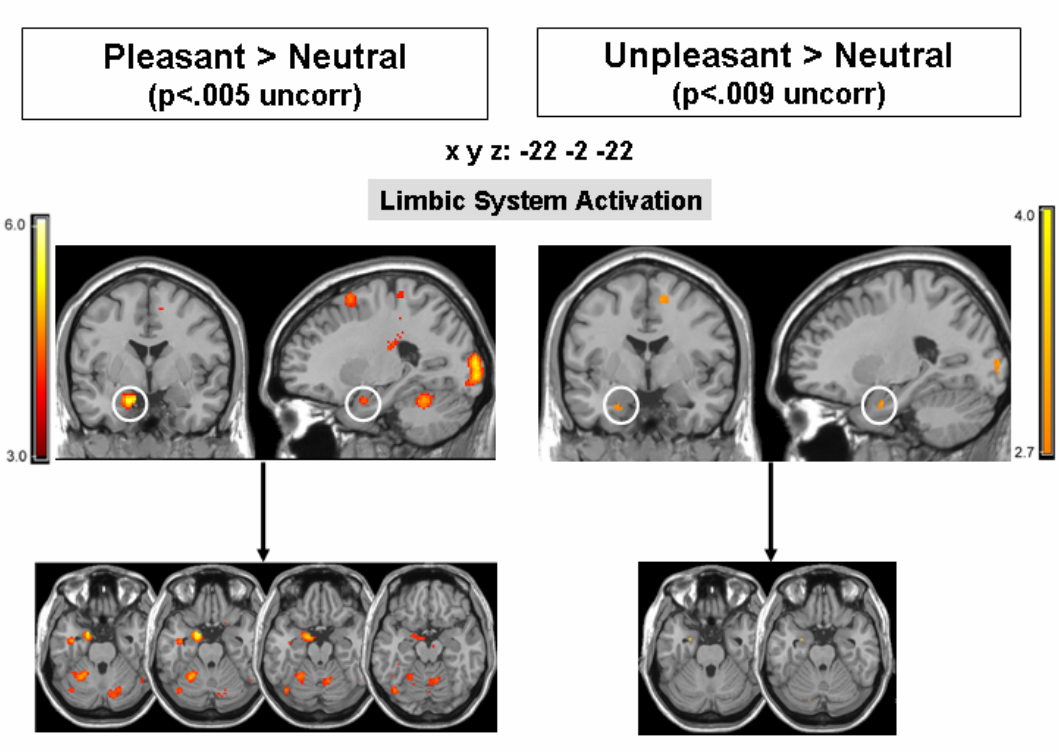
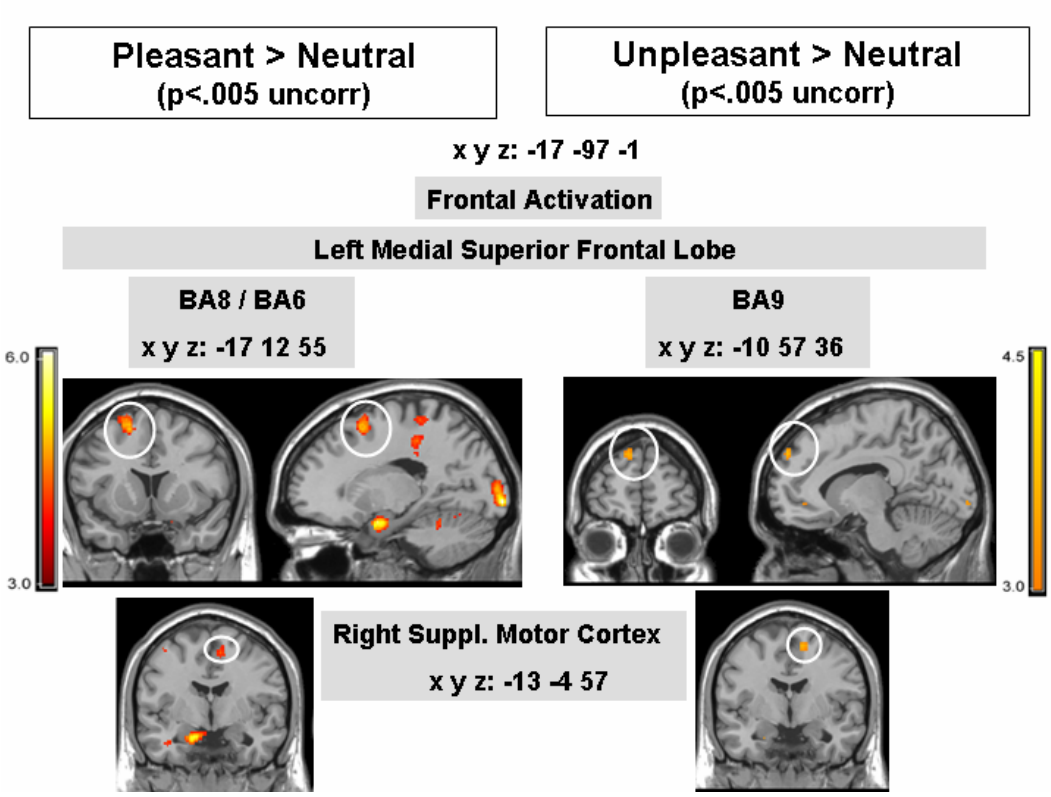


Figure 4c: *Frontal activation comparing pleasant against neutral (left upper panel as well as bottom panel) and unpleasant against neutral adjectives (right upper and lower panel).*

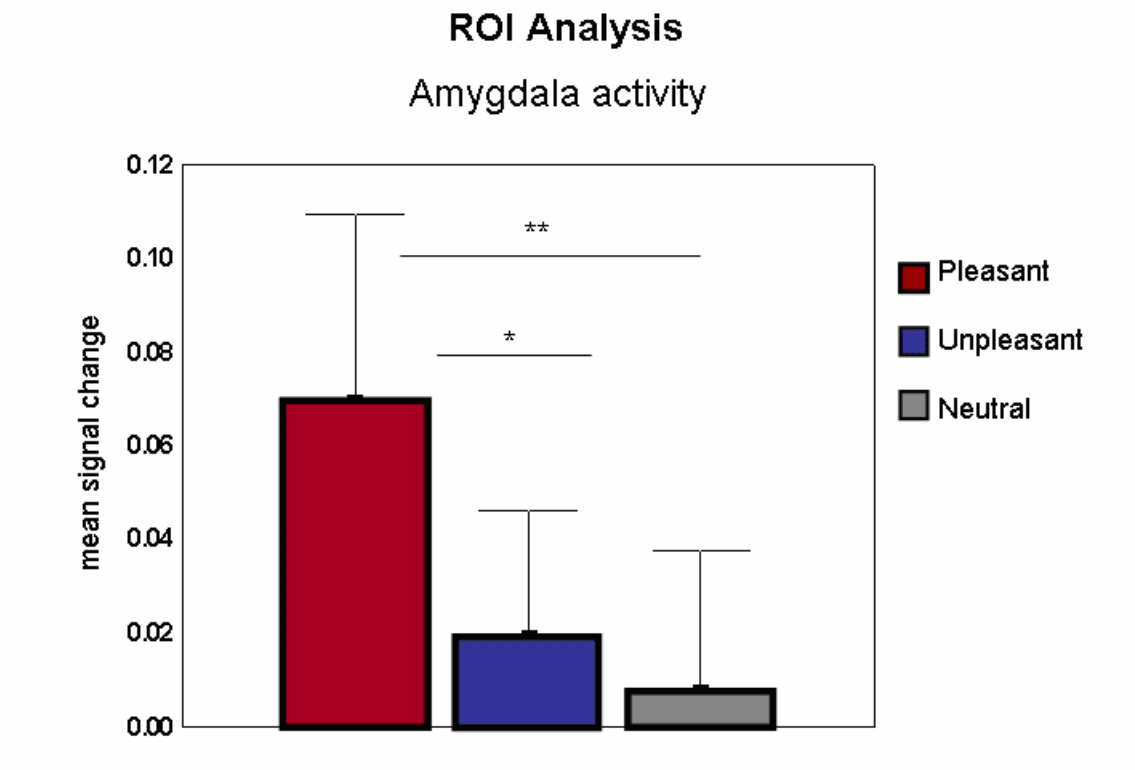


C. ROI Analysis

Significant activation of the amygdala during viewing of pleasant adjectives was confirmed by region of interest analysis (ROI). Statistical analysis (ANOVA) yielded significantly stronger mean signal change in the amygdala for pleasant compared to unpleasant and neutral word categories ($F(2,28) = 6.0$, $p < .005$; pleasant > neutral: $F(1,14) = 16.2$, $p < .001$; pleasant > unpleasant: $F(1,14) = 5.7$, $p < .05$).

Results from ROI analysis of the amygdala are presented in Figure 5.

Figure 5: *Mean signal change in the amygdala during viewing pleasant, unpleasant, and neutral adjectives. Asterisks describe significant post hoc interactions. Mean signal change was estimated from significant mean beta values of individual contrasts comparing each word category against the baseline condition. Beta values were exported within a sphere of 3 mm around the local peak maximum intensity defined by an anatomical mask of the left amygdala.*



D. Effects of emotional valence: (Pleasant > Unpleasant, Unpleasant > Pleasant)

Contrasting pleasant and unpleasant adjectives against each other corroborated a stronger impact of pleasant adjectives. Activation in the left amygdala, the left anterior parahippocampus and the left visual cortex was still sensitive to pleasant valence. Again, a stronger impact of parietal regions occurred. Moreover, a stronger increase in infero-temporal visual areas and temporal brain regions in the right hemisphere was found. Temporal regions comprised the right anterior temporal pole, and superior (BA 21), middle (BA 37) and inferior temporal brain areas indicating a contribution of the right hemisphere in the evaluation of pleasant meaning.

Besides an increase in the right occipital cortex, no other brain regions showed stronger activation when unpleasant adjectives were contrasted against pleasant adjectives.

A synopsis of significant effects for pleasant greater unpleasant contrasts is illustrated in Table 9a and Figure 6.

Table 9: *Significant effects of highest activated voxels within each brain region obtained for contrasts comparing pleasant against unpleasant adjectives (**Table 9a**), and unpleasant against pleasant adjectives (**Table 9b**). SPM99, random-effects analysis, n = 15, p < .005 uncorrected, T > 2.98, k>4.*

Table 9a: Pleasant > Unpleasant

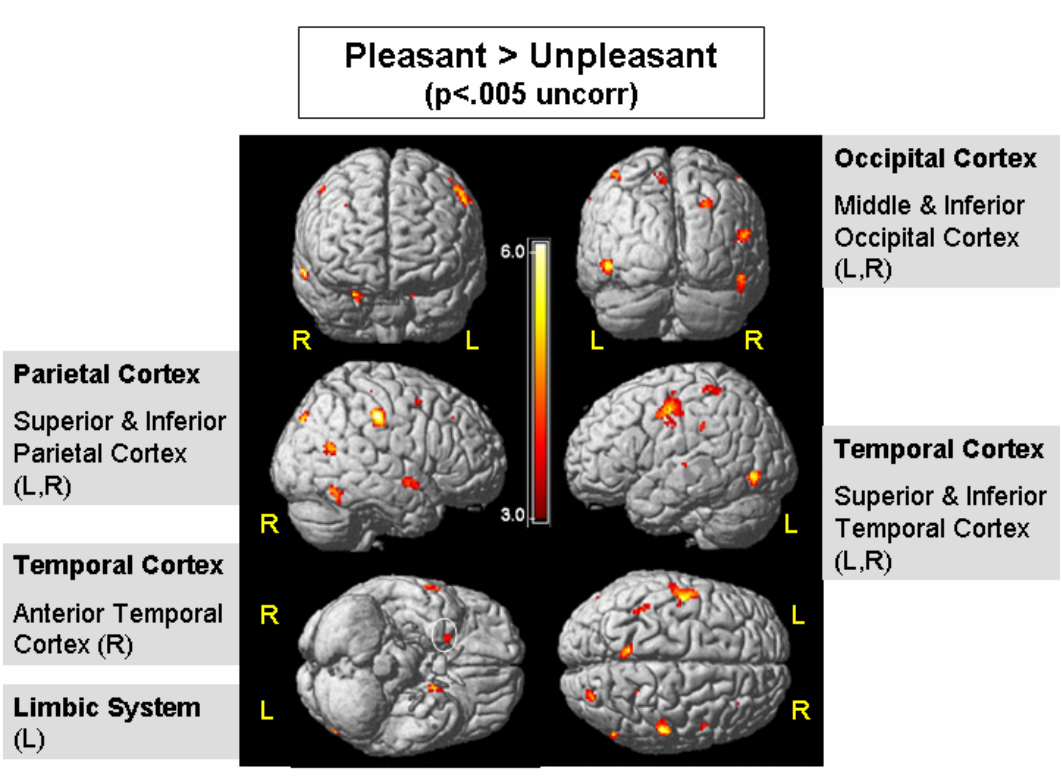
Hemi sphere	*Brain Region*	*Brodman (BA)*	*T - Value*	*Coordinates x, y, z MNI*	*Cluster*
Left	Inferior Occipital Lobe	BA 19	4. 37	-46 -72 -6	73
Left	Precentral	BA 6	3. 39	-52 0 42	69
Left	Precentral	BA 3	3. 90	-38 -10 36	
Left	Postcentral	BA 4/6	4. 10	-54 -10 48	137
Left	Postcentral	BA 4	3. 50	-54 -18 52	
Left	Postcentral	BA 2	3. 28	-42 -42 62	24
Left	Supramarginal Gyrus	BA 2	3. 87	-48 -36 34	10
Left	Parietal Lobe, Precuneus	BA 5	3. 82	-10 -52 60	59
Left	Superior Temporal Gyrus	BA 21/22	3. 13	-60 -22 4	4
Left	Middle Frontal Lobe	BA 6	3. 15	-24 -2 42	4
Left	Limbic Lobe: Parahippocampus		3. 77	-16 2 -24	41
	Amygdala			-22 2 -24	
Right	Superior Occipital Lobe	BA 19	3. 88	26 -82 40	32
Right	Parietal Lobe,	BA 2/3	4. 71	50 -26 40	135

Right	Postcentral, Supramarginal Parietal Lobe, Precuneus	BA 5	3. 48	24	-46	46	15
Right	Anterior Temporal Pol	BA 28/38	3. 54	26	12	-24	42
Right	Superior Temporal Gyrus	BA 21	5. 21	64	-2	-10	32
Right	Middle Temporal Gyrus	BA 37	3. 67	53	-60	16	50
Right	Inferior Temporal Lobe	BA 37	3. 53	50	-58	-16	57
Right	Inferior Temporal Lobe, Fusiform Gyrus	BA 37	3. 21	44	-48	-20	
Right	Middle Frontal Gyrus, Precentral	BA 3/6	3. 78	50	6	52	8

Table 9b: Unpleasant > Pleasant

Hemi sphere	***Brain Region***	***Brodman (BA)***	***T - Value***	***Coordinates x, y, z MNI***			***Cluster***
Left	Middle Occipital Lobe	BA 39	3. 62	38	-78	18	8

Figure 6: *Brain activation elicited during contrast comparing pleasant against unpleasant adjectives. For visualization of effects, functional brain activation maps (spmT-images) are superimposed on a single subject T1-weighted image from the SPM canonical image space displayed at a threshold of p <.005 (uncorrected), with a spatial extend threshold of 4 contiguous voxels. L (left side) and R (right side).*



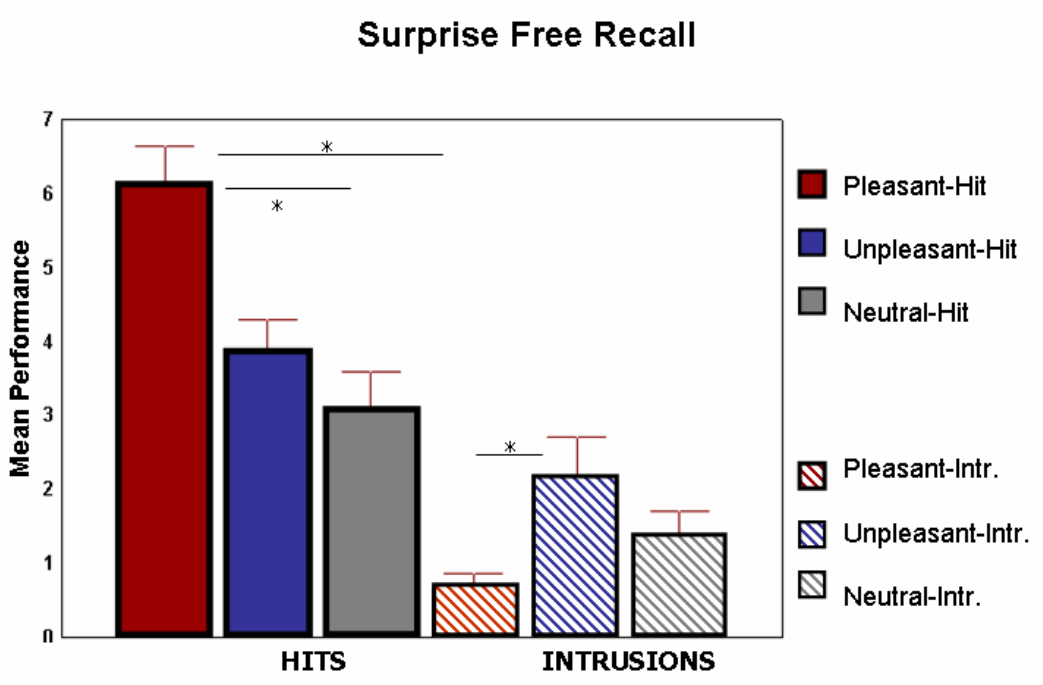
4.2. Memory performance

4.2.1. Behavioural data

In the surprise free-recall test emotional adjectives were recalled better than neutral ones as revealed by significant main effects of 'Valence' ($F(2,28) = 13.7$, $p < .01$). Post hoc tests showed that especially pleasant adjectives were better and also more accurately remembered than unpleasant and neutral words ('Valence': pleasant > neutral: $F(2,28) = 23.6$, $p < .001$; pleasant > unpleasant: $F(2,28) = 12.9$, $p < .005$; 'Intrusions': pleasant > neutral: $F(2,28) = 3.1$, $p < .06$). Unpleasant adjectives did not differ from neutral words and more unpleasant than pleasant adjectives were erroneously remembered as 'old' ('Valence': pleasant > unpleasant: $F(2,28) = 2.1$, $p > .16$; 'Intrusions': unpleasant > pleasant: $F(2,28) = 5.3$, $p < .05$).

Memory performance is shown in Figure 7.

Figure 7: *Memory performance of correctly (Hits) and erroneously (Intrusions) remembered unpleasant, pleasant and neutral words during a surprise free recall test at about 50 minutes after scanning. Significant post-hoc interaction effects are illustrated by asterisks.*



5. Discussion

The primary objective of the present fMRI study was to delineate brain structures involved in the facilitated processing of highly arousing pleasant and unpleasant in contrast to neutral, low arousing words. A passive viewing context of silent word reading was employed to study emotion effects occurring spontaneously without influence from additional task demands. Methodologically, an event-related fMRI design was chosen to examine emotion effects related to the initial phase of word perception. Only healthy subjects without prior history of affective disorders were examined. Memory performance of words was tested by way of a surprise free recall test to examine long-term effects of emotional word encoding on memory.

5.1. Lexicality effects (Words > Baseline)

In line with the view that words grab attention automatically, previous empirical research on single word processing has shown that silent reading of words increases activation in brain regions involved in word recognition (ventral visual processing areas), the modulation of

attention (cingulate and parietal cortex) and the analysis of a word's semantic aspects (e.g., temporal and infero-frontal brain regions (e.g., Posner et al., 1997 for an overview). Silent reading of adjectives was associated with activation in a number of brain regions including occipital and infero-temporal, superior temporal, parietal and inferior prefrontal and cingulate cortex areas. The activation patterns accord with previous imaging results of single word processing (e.g., Posner et al., 1997) and suggest that adjectives had been recognized, attended to and comprehended.

5.2. Effects of Emotionality

5.2.1. Emotional adjectives > Neutral adjectives

Comparing highly arousing emotional adjectives with low arousing neutral adjectives revealed that emotion specific activity was most prominent in visual sensory cortex areas as well as in limbic nuclei comprising the left amygdala and adjacent anterior parahippocampal regions. The localization of limbic activity is consistent with anatomical findings and functional imaging results suggesting strong feedback projections between the amygdala and the anterior parahippocampus (e.g., Amaral et al., 1992; Pitkanen, Pikkarainen, Nurminen, & Ylinen, 2000) during the encoding of emotional stimuli (e.g., Dolcos et al., 2003; LaBar, Gitelman, Parrish, Kim, Nobre et al., 2001). Additional activation included bilateral parietal cortex and premotor areas in the superior prefrontal cortex.

In the visual cortex facilitated perceptual processing of emotionally pleasant and unpleasant adjectives included secondary visual association areas in the left middle occipital gyrus as well infero-temporal cortex areas in the left fusiform gyrus. Studies of silent word reading have shown that during the initial phase of word perception blood flow in the right and specifically in the left visual cortex increases significantly (e.g., Posner et al., 1997). Regions in the left middle occipital cortex become activated when subjects encode lexical features such as word form (e.g., Nobre et al., 1994). Activation in left extrastriate cortex regions such as the fusiform gyrus progresses substantially for meaningful words in contrast to pseudowords or letter strings suggesting a special role of the left fusiform gyrus in the encoding of meaningful verbal concepts (e.g., Gaillard et al., 2006b; Nobre et al., 1994, Martin-Loeches et al., 2001).

Previous imaging studies provided evidence for the view that the amygdala improves the perception of emotionally significant stimuli: When subjects are confronted with highly aversive words, angry and happy faces or highly arousing unpleasant and pleasant pictures, these stimuli have been demonstrated to enhance activity in the ventral visual processing stream and the

amygdala (e.g., Breiter, et al., 1996; Isenberg et al., 1999; Lane et al., 1999; Liberzon et al., 2003; Keightley et al., 2003; Mourao-Miranda et al., 2003; Sabatinelli et al., 2005; Tabert et al., 2001). The results suggest that once the amygdala attributes significance to an incoming stimulus it amplifies visual processing of this stimulus along the entire ventral visual processing stream via its direct feedback projections to the visual cortex. Facilitated perception of emotional items has been associated with states of enhanced 'perceptual vigilance' and 'motivated attention' to emotionally salient stimuli observed in several emotion studies in the presence of emotionally highly arousing emotional stimuli (e.g., Bradley et al., 2000; Lang et al., 1997a for reviews). Emotional arousal has proven as critical for both enhanced visual processing of emotional stimuli and the degree of amygdala engagement (e.g., Bradley et al., 2003; Phan et al., 2003, 2004; Williams et al., 2001; Sabatinelli et al., 2005). This type of arousal-driven, 'natural selective attention' or 'motivated attention' to emotional stimuli (cf. Lang et al., 1997a, pp.97) may be engaged when humans process emotional pictures, faces or symbolic representations rated as highly arousing, such as the emotional adjectives used here. However, besides arousal the current results attest an impact of pleasant valence on amplified amygdala activation and sensory processing.

5.2.2. Effects of positive valence on word processing (Pleasant > Neutral, Pleasant > Unpleasant)

Although emotional adjectives were matched for perceived arousal, pleasant adjectives as opposed to neutral and unpleasant adjectives produced the strongest signal increase in the amygdala and in extended extrastriate cortex regions (e.g., fusiform gyrus) suggesting an amygdala-driven perceptual processing advantage for highly arousing adjectives with positive relevance. Contrasting pleasant against neutral as well as pleasant adjectives against unpleasant adjectives showed that the activation pattern in the left middle occipital cortex as well as in the left infero-temporal, fusiform gyrus and also in limbic structures was strongest for pleasant compared to neutral and unpleasant adjectives. The stronger increase in subcortical limbic brain areas was confirmed by region of interest analysis indicating significantly stronger amygdala activation for pleasant than for neutral or unpleasant adjectives.

Pleasant adjectives also lead to significant signal increase in a variety of other posterior cortical brain regions reflecting stronger attentive and elaborative processing of pleasant words than words of any other word category (neutral and unpleasant). In posterior brain regions activation included parietal and anterior temporal brain areas. Parietal cortex activation comprised brain areas that form part of the brains attention network such as the middle and posterior cingulate

cortex as well as brain areas in the somatosensory and superior and inferior parietal cortex (e.g., Corbetta et al., 1999, 2002; Posner et al., 1990). A stronger increase in these somatosensory and parietal cortex regions occurs when subjects shift and direct attention to the location of specifc target stimuli (Corbetta et al., 1998) and has also been observed during passive viewing conditions (e.g., Shulman, Corbetta, Buckner, Raichle, Fiez et al., 1997 for review). Previous emotion studies have found enhanced parietal cortex activation during visual search or visual detection tasks as well as in task where subjects had to attend, memorize or ignore an emotional target stimulus (e.g., words, pictures) corroborating the view of strong interactions between emotion and attention systems (e.g., Canli et al., 2004; Cato et al., 2004; Compton, Banich, Mohanty, Milham, Herrington et al., 2003; Junghöfer et al., 2006; Kensinger et al., 2004). In line with the overall stronger visual processing effects of pleasant adjectives, the engagement of parietal cortex regions in the current study implies that participants spontaneously directed attention to pleasant words more strongly than to neutral or unpleasant words suggesting facilitated processing of pleasant words in both the ventral visual processing stream responsible for object recognition and the dorsal visual processing stream responsible for object location (e.g., Ungerleider et al., 1982, 1994; see also in the General Introduction on pp. 23-24).

Contrasting pleasant against unpleasant words revealed an increase in infero-temporal visual areas and anterior temporal as well as superior and middle temporal brain regions in the right hemisphere. A participation of superior temporal and middle temporal lobe regions in the right hemisphere has been attributed to an enhanced elaborative processing of a word's connotative meaning (e.g., Bottini, Corcoran, Sterzi, Paulesu, Schenone, et al., 1994; Beeman, Friedmann, Grafmann, & Perez, 1994). Anterior temporal regions are regarded to play a role in higher-order visual object recognition and memory processing. Intracranial field potential studies suggest that anterior temporal lobe activation during word processing corresponds with activation of the electrocortically measured N400 potential that has been associated with higher-order semantic meaning processing (McCarthy, Nobre, Bentin, & Spencer, 1995; Nobre & Plunkett, 1995). Moreover, the anterior temporal lobe receives input from limbic structures such as the amygdala and the hippocampus (Pandya et al., 1985) rendering these brain areas to be sites for the integration of emotional information in the current context and in memory. Concerning emotion studies, activity in anterior temporal regions has been reported during viewing of unpleasant and pleasant pictures and words and during the retrieval of affect-laden autobiographical information from memory (e.g., Fink, Markowitsch, Reinkemeier, Bruckbauer, Kessler et al., 1996; Crosson et al., 1999, Lane et al., 1997a, 1999). Accordingly, a stronger activation of anterior temporal lobe regions during affective processing has been related to a more detailed evaluation of a

stimulus` emotional meaning. As such, it occurs at later stages of visual analysis when perception is completed and may involve the retrieval of semantic information from memory (e.g., Lane et al., 1997a; 1999).

Taken together, the visual brain activity pattern suggests that when participants spontaneously viewed arousing emotional and low arousing neutral adjectives, emotionally arousing pleasant adjectives benefited from an amygdala modulated perceptual processing advantage and pleasant contents took advantage of a more detailed attentive and elaborative meaning processing.

What may this pleasure preference involving the amygdala be attributable to? Today, there is ample evidence that the amygdala responds to stimuli with both strong unpleasant and pleasant motivational relevance including highly arousing pleasant and unpleasant words (Hamann et al., 2002; for review see Phan et al., 2002; Sander et al., 2003, Zald, 2003). Unpleasant stimuli can be relevant to individuals because of their inherent survival value signalling danger and aversive consequences. Pleasant stimuli can be relevant because of their intrinsic pleasantness inviting us to approach and anticipate rewarding positive outcomes (Lang et al., 1997a; cf. Sander et al., 2003; pp. 311). It has been noted, that healthy subjects show a tendency for positive affect that biases emotional processing toward pleasant rather than unpleasant stimuli. This bias can covary with the amount of affective arousal (e.g., Cacioppo, 2004; Ito et al., 1998b, 2005), task demands (e.g., Zajonc, 2001), current motivational needs (LaBar et al., 2001) as well as individual personality traits (e.g., Canli et al., 2001, 2002, 2004; Ito & Cacioppo, 1995).

Concerning emotional arousal, Cacioppo and colleagues, for instance, assume that our motivation to approach is stronger than that to avoid at low and moderate levels of arousal. Likewise, Zajonc (2001) suggests that in the absence of strong aversive primary reinforcers such as is the case in tasks with mere stimulus exposure, we tend to prefer pleasant material. It may be that in contrast to direct confrontations with emotionally challenging objects, words despite being rated as highly arousing induce lower levels of physiological arousal thereby promoting a pleasure preference in passive viewing conditions. Moreover, a preference for pleasant words may be more likely when stimuli are controlled for arousal because a stronger response bias to aversive words having greater average arousal intensity than pleasant ones is avoided (Ito et al., 1998b). Nevertheless, emotional arousal has been shown to be critical for both early visual processing of emotional stimuli as well as the extent to which this stimulus-driven early selection of emotional stimuli is modulated by the amygdala. (e.g., Bradley et al., 2003; Phan et al., 2003, 2004; Williams et al., 2001; Sabatinelli et al., 2005). Recent imaging findings however indicate that positive valence like emotional arousal contribute to amygdala mediated enhanced visual activation: When subjects passively viewed pictures varying systematically in valence and

arousal, pleasant, but low arousing pictures and arousing pictures alike elicited the amygdala and lead to stronger signal increase in occipital and infero-temporal visual cortices (Mourao-Miranda et al., 2003). In the current experiment the findings suggest that the combination of both the emotional arousal intensity of the pleasant adjectives and their pleasant content contributed to the stronger processing effect for pleasant adjectives. To specify the interaction between emotional arousal and valence further, future imaging studies are needed. Incorporating unpleasant and pleasant words with low, moderate and high levels of arousal may help to examine whether amygdala and visual cortex activation increases or decreases lineary as a function of stimulus valence and/or the amount of a word's emotional arousal.

Concerning the influence of motivational states and individual differences in affect on emotional processing, previous imaging studies demonstrated that pleasure preferences are modulated by the amygdala. LaBar (2001) have found that in states of hunger food-related pictures are processed preferentially by inducing activation in the amygdala, the anterior parahippocampus and the fusiform gyrus. The results suggest that emotional perception is biased by the current motivational state of the individuals. Motivational engagement in the processing of pleasant as opposed to unpleasant words has also been reported by Hamann and Mao (2002) who found that associative processing of highly arousing pleasant words enhanced activation in the amygdala and in reward-related brain structures. As far as individual differences are concerned, comparisons of depressive with healthy subjects have shown that healthy controls exhibit stronger amygdala activity to pleasant than to unpleasant words and pleasant words are responded to faster than unpleasant ones (Canli et al., 2004). In two other studies the same authors replicated stronger amygdala engagement in the processing of happy faces than neutral faces and pleasant than unpleasant pictures in healthy extraverted subjects (e.g., Canli et al., 2001, 2002). Taking these findings into account, the current study suggests that such pleasure preferences may also hold for healthy student subjects with low levels of trait and state anxiety and no history of negative affect as indicated by low state and trait anxiety and low depression scores in student participants. Adjectives certainly induced affective and motivational states. Highly arousing pleasant adjectives described positive motivational states and positive traits (e.g., in love, sexy, successful, charming, happy, exciting, chilling, healthy, etc.) whereas unpleasant adjectives described negative motivational states and traits (e.g., brutal, ugly, anxious, nervous, sad, lonely, etc.). In healthy student subjects emotional adjectives associated with pleasant motivational states may have stronger self-relevance, motivational incentive and rewarding character than unpleasant adjectives and thus may be processed preferentially. Similar considerations have been put forward by other authors proposing a specific involvement of the

human amygdala in the appraisal of biologically relevant as well as individually relevant emotional stimuli (Sander et al., 2003).

5.2.3. Prefrontal emotion effects

Viewing pleasant and unpleasant adjectives in contrast to neutral ones also increased BOLD responses in superior prefrontal lobes. Prefrontal activation included superior frontal cortex areas (BA 9) in the left hemisphere and was most prominent in medial areas of the secondary motor (BA 8) and premotor cortex areas (BA 6) in the left and right frontal hemisphere. Again, emotion effects were most pronounced for pleasant adjectives in contrast to unpleasant and neutral adjectives. Activity in superior frontal cortex areas (BA 9) has been associated with a variety of processes attributable to consciously controlled (e.g., Hariri et al., 2000; Ochsner et al., 2002; Lane et al., 1997b) and internally generated emotional evaluation (e.g., Reiman, Lane, Ahern, Schwartz, Davidson et al., 1997), emotion-related decision making (e.g., Bechara, Damasio, Tranel, & Anderson, 1998) and the planning of emotional responses (e.g., Tucker, Luu, & Pribram, 1995). Frontal motor regions (e.g., BA 6, BA 8, and supplementary motor cortex) are specifically related to the planning of movements elicited by external (especially visual) cues. Stimulation here elicits complex motor activity such as vocalisation, rhythmic leg movements, chewing, swallowing, or contortions of the body. When persons silently read 'action words' that describe the execution of a specific movement (e.g., lick, pick, or kick, etc.), blood flow increases in the lateral and medial premotor cortex as well as in those areas of the motor cortex activated during direct execution of this movement (e.g., Hauk, Johnsrude, & Pulvermüller, 2004). Furthermore, silent naming of objects and their respective usage increases activity in the left dorsal premotor cortex, the left ventral premotor cortex and the left supplementary motor area (Grafton, Fadiga, Arbib, & Rizzolatti, 1997). Based on these findings, it has been proposed that words with strong behavioural relevance are capable of eliciting corresponding actions and sensations (e.g., Hauk, et al., 2004; Grafton et al., 1997). Emotions have been defined as action disposition preparing the organism to respond adequately to environmental stimuli either by approaching or by avoiding (e.g., Lang et al., 1997a). Because of their highly stimulative nature emotional adjectives, particularly pleasant ones, thus may lead to increased preparation for action enhancing activity within brain regions associated with evaluative decision making (BA 9) and action planning (premotor and supplementary cortex areas). Similar conclusions have been drawn by Isenberg and associates (1999) using threat words. In this imaging study threat

words increased activity in the amygdala, visual and premotor cortex areas in contrast to neutral words. The current data extend these findings to the processing of pleasant words.

5.2.4. Activation of the cerebellum in emotional word processing

Yet another brain structure showed strong signal increase that was most pronounced in the contrasts comparing emotional against neutral adjectives, namely the cerebellum. Beyond its important role in motor functions, several authors have made alternative suggestions underscoring the cerebellum`s strong functional connectivity with other brain structures (Schmahmann & Sherman, 1998; Allen, McColl, Barnard, Ringe, Fleckenstein et al., 2005). Investigating patients with damage to the cerebellum, Schmahmann and Sherman (1998) found severe impairment of executive functions such as planning, verbal fluency, abstract reasoning, and working memory. Moreover, these patients had difficulties with spatial attention and suffered from severe personality changes associated with blunting of affect. Imaging studies show that fluctuations in MR signal in the cerebellum correlate with signal fluctuations in thalamic, limbic, striatal, parietal and frontal cortices. Hence, it has been suggested that the cerebellum acts as a 'relay station' improving the processing speed of a variety of subprocesses involved in cognitive, affective, sensory and motor processing (Allen et al., 2005). Thus, a tentative proposal for the cerebellar activity found in the present study could be that it signals the degree of automaticity with which a word can be recognized, attended and responded to. Moreover, cerebellar activity appears to be facilitated when words convey emotional in particular pleasant meaning.

5.2.5. Laterality effects in emotional word processing

Traditional models claim that emotion and language functions are lateralized. Concerning language processing, the left hemisphere has long been regarded the language dominant cerebral hemisphere (Geschwind & Galaburda, 1985). Concerning emotional processing, two influential theories of emotional asymmetry have been proposed. The right hemisphere hypothesis posits that the right hemisphere is dominant over the left hemisphere in the perception, processing and expression of emotions (e.g., Hellige, 1993). The valence hypothesis states that hemispheric modulation depends on emotional valence: The right hemisphere is dominant for negative emotions and the left hemisphere is dominant for positive emotions (e.g., Davidson, 1992). The current activation pattern revealed no clear hemisphere-dominant emotion specific effects.

Visual cortex activation was predominantly left-lateralized for both pleasant and unpleasant words in contrast to neutral adjectives. Prefrontal emotion effects involved left superior frontal cortex areas (BA 9) and medial premotor regions in both hemispheres. For unpleasant compared to neutral words premotor activation was stronger in the right hemisphere whereas a stronger left-hemisphere involvement occurred for pleasant adjectives. Contrasting pleasant adjectives against unpleasant adjectives showed an involvement of right parietal and temporal hemisphere regions in the evaluation of pleasant emotional meaning. In sum, the activation pattern neither supports traditional models of language lateralization nor of emotional lateralization that hypothesize either a stronger contribution of the left hemisphere in the processing of language and pleasant emotion or a stronger right hemisphere dominance in the processing of unpleasant stimuli or emotion per se. By contrast, the results rather imply that both hemispheres have access to perceptual information whether lexical or emotional. Word processing studies support these claims and emotion studies concur, providing evidence for a stronger interhemispheric communication and dual coding of lexical and emotional information in both cortical hemispheres (Compton et al., 2005; Windmann et al., 2002, Lane et al., 1999; Mohr, Pulvermüller, & Zaidel, 1994; Neininger & Pulvermüller, 2003).

As far as subcortical emotion effects are concerned, limbic system activation was clearly left lateralized. Prior neuroimaging studies indeed do not conform closely to any of the propagated emotion models outlined above. Regarding unpleasant visual stimuli amygdala responses to picture stimuli are either left-lateralized or bilateral with no clear pattern obtained for pleasant pictures. For words a stronger left lateralized activation pattern of the amygdala and adjacent limbic regions has been reported in response to pleasant and unpleasant words (e.g., Phelps, 2004; Zald, 2003 for an overview). Phelps et al. (2001), for instance, assume that these subcortical laterality differences are related to the fact that the left amygdala responds more strongly to emotional cues that have been learned through cognitive processes or by language while the right amygdala mediates emotional responses to biologically prepared stimuli such as fearful faces or unpleasant pictures. Additional variables have been stressed by several other researchers who assume that differences in stimulus presentation and temporal dynamics may conform more closely to subcortical laterality effects than differences in emotional valence or stimulus material (e.g., in Zald, 2003). Consciously processed emotional stimuli have been shown to activate the left amygdala and emotional stimuli processed below the level of awareness have been found to activate the right amygdala (e.g., Morris, Öhmann, & Dolan, 1998b). Furthermore, amygdala responses show differential phasic and tonic activity over time

with stronger habituation in the right amygdala relative to the left amygdala (e.g., Whalen, Rauch, Etcoff, McInerney; Lee et al., 1998; but see Tabert et al., 2000).

Sex differences have also been discussed in the literature. Generally it is hypothesized that cognitive as well as affective processing are more lateralized in males than in females with respect to both cortical and subcortical activation. However, a recent metaanalysis on gender differences has found no clear evidence in support of this view (Wager, Phan, Liberzon, & Taylor, 2003). Concerning subcortical activation the metaanalysis yielded a stronger contribution of the left amygdala than the right one in affective processing in both sexes. Whether the stronger contribution of left limbic structures in the current study actually reflects a generally stronger contribution of left subcortical structures in the processing of pleasant emotional, verbal material or is attributable to other factors such as conscious stimulus presentations or a combination of both and additional factors is clearly a matter of debate and future investigations.

5.3. Emotional Memory Effects

Commensurate with the amplified processing of pleasant adjectives during word reading, pleasant adjectives were also better and more accurately remembered than unpleasant and neutral adjectives as indicated by the free recall test, 50 minutes after word viewing. Enhancing effects of emotional processing on long-term memory have been demonstrated in a large number of behavioural, electrophysiological, and imaging studies (see General Introduction on pp. 26 – 30 and Chapter 2 for an overview). In general, findings reveal that healthy subjects are more likely to remember highly arousing emotional than low arousing neutral stimuli (e.g., Bradley, 1994; Hamann, 2001; LaBar et al., 2006; Phelps, 2004 for reviews). Imaging studies with healthy subjects provide evidence that the amygdala modulates emotional memory by enhancing stimulus encoding and consolidation processes by virtue of its direct reciprocal connections with medial temporal lobe memory systems (MTL). All these studies have found that better recall of highly arousing emotional stimuli is associated with activation of the amygdala (e.g., Canli et al., 1999, 2000) and adjacent MTL regions (e.g., anterior parahippocampus and the hippocampus) during successful encoding of words and pictures that would later be correctly remembered (e.g., Dolcos et al., 2004; Hamann et al., 1999; Kensinger et al., 2004; Kilpatrick et al., 2003). This amygdala mediated memory enhancement may appear relatively automatic to guarantee an immediate impact of emotion on memory encoding processes and is most pronounced for stimuli rated as highly arousing (e.g., Canli et al., 2000; Hamann et al., 2001; Kensinger et al, 2004). Effects have been reported for immediate recall at about 10 - 15 minutes after study (e.g.,

Hamann et al., 2001; Kensinger et al., 2004) and for longer retention intervals of about 54 minutes, 3 weeks and even months (e.g., Hamann et al., 1999; Dolcos et al., 2004; Kilpatrick et al., 2003).

Although our design does not allow a direct correlational analysis between imaging and behavioural data because of too few trials for averaging it may be reasonable to assume that better recall of arousing pleasant adjectives was reflected in the stronger processing effects for pleasant adjectives at study. Specifically, the activation of the left amygdala and adjacent left memory regions such as the anterior parahippocampus and the involvement of anterior temporal lobe structures may have indicated the interactions between emotional and mnestic subcortical and cortical regions during the encoding of pleasant adjectives.

6. Conclusion

In our daily life we often learn about the potentially dangerous or rewarding attributes of objects, people and social situations by means of language, leading theorist to assume that language development played an important role in conveying and expressing emotions in the evolution of men (e.g., Damasio et al., 1992; Reisenzein, 1998; Tucker, 2001).

The current fMRI study investigated the functional activation patterns associated with the selective processing of highly arousing emotional words in a silent reading context. In line with the view that emotional stimuli initially engage attention and obtain priority in processing (e.g., Lang et al., 1997a), facilitated processing of emotional adjectives was reflected in enhanced activity in brain areas with perceptual, emotional, attentional, semantic, mnestic as well as behavioural functions.

Silent reading of pleasant and unpleasant adjectives enhanced activation in primary and secondary visual cortex areas indicating facilitated perceptual processing of arousing emotional in contrast to low arousing neutral words in the left visual cortex. In contrast to unpleasant and neutral adjectives, pleasant adjectives increased activation in left and also in right infero-temporal visual brain areas and augmented activity in limbic structures including the left amygdala. The results suggest that during passive viewing especially pleasant adjectives benefited from the rich 'upstream' and 'downstream' neural connections between the amygdala and the ventral visual processing stream indicating enhanced perceptual vigilance to adjectives with high arousal and pleasant valence. Moreover, pleasant adjectives were also subjected to a more attentive and detailed meaning evaluation as indicated by amplification of activation in bilateral parietal as well as anterior and superior temporal brain regions.

In line with the theoretical consideration of emotions as 'action dispositions', activation in superior prefrontal brain areas indicated a stronger response preparation during silent reading of pleasant but also unpleasant words in contrast to neutral adjectives. Emotional adjectives had both immediate effects on stimulus processing and long-term effects on memory. Even in conditions such as making subjects not explicitly remember stimuli at study, highly arousing emotional adjectives enjoyed a significant memory advantage which was most pronounced for highly arousing words with pleasant meaning. Better recall of pleasant adjectives accords with the stronger encoding of pleasant adjectives in the amygdala and adjacent parahippocampal as well as anterior temporal regions bolstering a broader and more extensive representation of pleasant information than unpleasant and neutral material in memory.

The relatively stronger contribution of the amygdala in enhanced visual processing of arousing pleasant adjectives in contrast to similarly arousing, but unpleasant adjectives corroborates previous findings of amygdala activation during the processing of pleasant stimuli, and observations of a stronger 'pleasure bias' in the processing of emotion laden material in healthy adults. The results also accord with previous findings predicting a stronger involvement of the amygdala during implicit processing than during explicit, cognitively controlled processing of emotional stimuli (e.g., Cunningham et al., 2003, 2004; Liberzon et al., 2000) and corroborate theoretical positions of the amygdala as a 'relevance' detector. According to this view, the human amygdala evolved from a primarily fear module processor to a 'relevance detector' alerting the organism initially toward stimuli symbolizing biological relevance, personal goals, current needs and individual preferences (Sander, et al., 2003).

Extending imaging findings from the processing of linguistic threat and active task conditions to the processing of verbal 'pleasure' and passive viewing conditions, the current fMRI study suggests that the usage of both unpleasant and pleasant verbal concepts allows interesting insights in how healthy individuals and their brains deal spontaneously and adaptively with arousing and motivationally relevant verbal information. Passive viewing and event-related fMRI designs appear most suitable to address these 'natural stimulus selection effects'.

V. Chapter 4[3]

Study 4: Motivational Priming: Modulation of the defensive startle reflex during emotional word processing - Insights from ERP and peripheral EMG eyeblink measures

1. Introduction

The eyeblink component of the human defensive startle reflex elicited by a sudden loud noise is sensitive to various manipulations of the context in which the startle eliciting tone is presented. Specifically, the processing of emotional stimuli has been shown to modulate the defensive startle reflex. When people view unpleasant pictures, the startle eyeblink has been found to be amplified and reduced during viewing pleasant pictures (e.g., Cuthbert et al., 1996; Lang et al., 1990 for an overview; Schupp, Cuthbert, Bradley, Birbaumer, & Lang, 1997; Vrana, Spence, & Lang, 1988). The impact of emotional processing on startle reflex modulation has been interpreted in terms of the motivational priming hypothesis (Lang, 1995) according to which emotions are viewed as action dispositions that prepare the organism to respond adaptively to environmental stimuli, ultimately improving survival by approaching or by avoiding certain stimuli. Thus, reflexes associated with an aversive response set such as the defensive startle reflex are facilitated during confrontation with unpleasant events and inhibited when exposed to pleasant events.

Apart from emotional additional experimental and cognitive factors influence the startle eyeblink response patterns in specific affective contexts: During emotional anticipation (e.g., Sabatinelli et al., 2001) or emotional imagery (e.g., Miller et al., 2002; Robinson & Vrana, 2000), startle facilitation has been found for pleasant and unpleasant events alike. These findings have been attributed to differences in processing demands (e.g., Miller et al., 2002). Whereas picture viewing requires perceptual processing of an external stimulus, text-driven emotional imagery involves internal associative memory processing, in which resources are directed away from perceptual processing and allocated toward internal, memory-based processing. Under such circumstances, the startle reflex is assumed to mobilize the organism to respond to significant changes in the environment by interrupting internally focused processes (e.g., Anthony & Graham, 1985; Graham, 1979; Miller et al., 2002). This sudden reactivation of the sensory systems is thought to lead to facilitation of the blink reflex. Indeed, the startle blink amplitude

[3] Parts of the current study are taken from an article already published by the author of the doctorial thesis.

has been found to be increased during internal cognitive activity (e.g., Panayiotou & Vrana, 1998) and the magnitude of startle potentiation during internal processing appears to vary with the depth of mental engagement (e.g., Miller et al., 2002).
The motivational priming hypothesis and related empirical findings of startle reflex modulation during affective picture viewing or emotional imagery have already been discussed in detail in the General Introduction (pp. 11 - 15).

1.1. Two measures of the defensive startle reflex

In addition to a startle eyeblink, startling tones also elicit an auditory evoked P3 in the event-related brain potential - the so-called probe P3 (e.g., Ford & Pfefferbaum, 1991; Putnam & Roth, 1990). Picture viewing studies that have simultaneously investigated affective modulation of the electromyographic (EMG) startle response and the auditory evoked probe P3 (e.g., Cuthbert et al., 1998; Schupp et al., 1997) have found that the P3 response to the startle tone is significantly attenuated when subjects are engaged in viewing either pleasantly or aversively arousing pictures. This arousal-driven probe P3 modulation pattern has been interpreted as a consequence of greater attentional engagement by highly arousing emotional pictures compared to low arousing neutral foreground pictures, such that fewer processing resources are left to process the startle tone (e.g., Schupp et al., 1997).

Emotional responses are also elicited by other types of visual stimuli such as emotional words. Similarities in the way the human organism deals with pictorial and linguistic emotion stimuli have been reported in that processing of emotional words and pictures alike has been found to be associated with larger brain event-related P3 and late positive components (LPP) responses than the processing of neutral stimuli (e.g., Chapman et al., 1980; Cuthbert et al., 2000; Keil et al., 2002; Naumann et al., 1992). Concerning peripheral physiological responses, processing of emotional words has been shown to induce similar, albeit less pronounced EMG corrugator and zygomaticus responses as the processing of emotional pictures (e.g., Larsen, Norris, & Cacioppo, 2003). Skin conductance is also increased in response to aversive in comparison to neutral words, both during subliminal and supraliminal word presentation (e.g., Silvert, Delplanque, Bouwalerh, Verpoort, & Sequeira, 2004). Together, the results suggest that emotional words are capable of eliciting bodily as well as physiological and cortical reactions similar to that elicited by concrete pictorial emotion stimuli, presumably by activating the brain's motivational systems of defense and approach. Theoretically, network models of emotion also propose an impact of

emotional word content on physiological responses. Linguistic expressions are assumed to be stored within semantic networks that encompass links to all aspects of their linguistic and pragmatic usage and emotional connotations (e.g., Bower, 1981; Lang, 1979). Thus, the word *gun*, for example, not only represents the instrument itself, but includes links to its operations, use, purpose, and consequences as well as their emotional evaluation. Lang and colleagues (1993) further assume that not only associated semantic but also physiological and motor response information is coactivated in such associative networks, lending further momentum to the hypothesis that physiological responses such as the startle eyeblink or probe P3 should be motivationally primed and modified by emotional language stimuli as foregrounds.

1.2. Affective modulation of the startle eyeblink during the processing of emotional words

Startle responses to fear-relevant verbal material have been investigated in recent studies. Aitken, Siddle and Lipp (1999) used threat and non-threat words with startle tone onset after 60 ms, 120 ms, 240 ms, and 2000 ms lead intervals in participants with normal, low, or high anxiety levels. The study yielded larger foreground effects for threat than for non-threat related words, that is, larger blink facilitation at 60 ms and larger inhibition at 240 ms lead intervals. These effects were somewhat more pronounced in highly anxious subjects. No significant impact of emotional category was found for either the 120 ms or the 2000 ms lead interval. In a similar study with highly anxious children, Waters, Lipp, and Cobham (2000) have found a tendency for larger startle eyeblink responses during threatening words at 60 ms lead intervals and some evidence of increased inhibition at 240 ms but no selective influence of emotional category at 3500 ms. These results are noteworthy in relationship to the literature on affective startle modulation with unpleasant emotional pictures as here reliable motivational priming effects are often found with lead intervals of 1000 ms and longer, with the largest facilitation occurring at about 3800 ms (see Bradley et al., 2006; Lang et al., 1997a and pp. 14 in the General Introduction for an overview). Moreover, the motivational priming hypothesis predicts that motivational priming of defensive reflexes should be largest during a ‘post-encounter’ stimulus processing stage characterized by shifting from stimulus orienting to ‘active attention’ and from ‘behavioural immobility’ to the preparation of aversively or appetitively motivated action tendencies. Effects of attentional engagement on startle response modulation during letter reading have been demonstrated by Lipp, Blumenthal, and Adam (2001): When subjects directed their attention to visually presented single letters in an active paradigm, responses to a suddenly appearing startling tone were facilitated at 60 ms and 3500 ms lead intervals and inhibited at 240

ms lead intervals. The results attest an impact of attention and task involvement for startle responses at longer lead intervals when perceptually relatively simple language stimuli are used as foregrounds.

Yet, another study exists, that investigated affective startle eyeblink modulation and visual ERP responses to briefly presented body-related, pain-related, and neutral adjectives in patients with prechronic pain and comparison subjects. Startle tones were presented at very short lead intervals of 1.25 ms after word-onset (Knost et al., 1997). Interestingly, these authors found generally enhanced startle eyeblink responses 1.25 ms after the onset of body- and pain-related adjectives in comparison to neutral adjectives. In parallel with the startle EMG results, both groups also had larger visually evoked late positive components (LPP) for body- and pain-related words. Auditory evoked potentials in response to the startle tone were not reported. The results suggest that at least during initial phases of processing, passive viewing of words dealing with personal threat and physical harm modulates the defensive startle eyeblink response.

Regarding healthy subjects, pleasant words and longer lead intervals, affective startle modulation with emotional words as foregrounds is, so far, a largely open question in the literature. Likewise, central nervous indices of startle tone processing (probe P3) have not been assessed with words as foregrounds, and the relationship between cortical processing of affective foreground stimuli as reflected in the visually evoked event-related potential and startle reflex physiology has, in general, scarcely been addressed.

Thus, the aim of the current study was to investigate the relationship of peripheral EMG and central nervous ERP indices of the human startle response at long lead intervals while healthy student subjects covertly evaluated the meaning of both, pleasant and unpleasant as well as neutral emotional adjectives.

2. Methods

2.1. Participants

Thirty-three healthy student volunteers (15 women, 18 men) received course credit or a financial bonus of 10 Euros for participation. Strong smokers (more than 20 cigarettes a day) were excluded from the experiment as heavy smoking influences startle amplitude (e.g., Postma, Kumari, Sharma, Hines, & Gray, 2001). The data of 4 participants had to be discarded because no measurable startle responses could be obtained. Data of another 3 participants had to be rejected from the analysis because of recording errors. The remaining 26 participants (10 women, 16 men; mean age: 26 years) were native speakers of German and right-handed as

determined by handedness scores on the Edinburgh Handedness Inventory (Oldfield, 1971). Upon interview, participants reported no drug abuse, neurological, mental, or chronic bodily diseases, or medication for any of these. All volunteers agreed to participate after reading a detailed consent form approved by the University of Konstanz Institutional Review Board.

2.2. Stimulus Material

180 adjectives (60 highly arousing pleasant, 60 highly arousing unpleasant, and 60 neutral, low arousing adjectives) were selected from a pool of about 500 German adjectives according to normative ratings of 45 student subjects who had judged the selected adjectives on the dimensions of perceived arousal and valence using the Self-Assessment Manikin (e.g., Lang, 1980; Lang et al., 1997b). The pleasant and unpleasant adjectives were matched for perceived arousal. They did not differ significantly from each other but differed significantly from the neutral adjectives on this dimension ($F(2,177) = 66.3$, $p < .001$). Adjectives were further selected to be comparable in mean word length ($F(2,177) = 0.24$, $p = .78$, and word frequency ($F(2,177) = 2.0$, $p = .14$). Word frequency was controlled using frequency counts for written language from the standardized word-database CELEX (Baayen et al., 1995).
Table 1 shows means and standard errors of the rating data in each emotional category.

Table 1: *SAM mean valence and arousal ratings of pleasant, neutral, and unpleasant adjectives rated by 45 students of the University of Konstanz.*

Mean Valence and Arousal Ratings	Adjectives		
	Pleasant	Neutral	Unpleasant
Valence	6.6 (.09)	4.7 (.08)	2.9 (.07)
Arousal	5.3 (.11)	3.8 (.12)	5.5 (.11)

The range and direction of the SAM ratings are as follows: pleasure = 9 (extremely pleasant) to 1 (extremely unpleasant), arousal = 9 (extremely arousing) to 1 (not at all arousing). Standard errors are in parentheses.

Table 2: *Frequency counts for written language from the standardized word-database CELEX of pleasant, neutral, and unpleasant adjectives.*

Mean Word frequency	Adjectives		
MannW	Pleasant	Neutral	Unpleasant
	52.4 (18.9)	41.5 (12.4)	15.9 (3.5)

Standard errors are in parentheses.

Table 3: *Mean word length of pleasant, neutral, and unpleasant adjectives.*

Mean Word length	Adjectives		
	Pleasant	Neutral	Unpleasant
	8.6 (.36)	8.3 (.33)	8.3 (.30)

Standard errors are in parentheses.

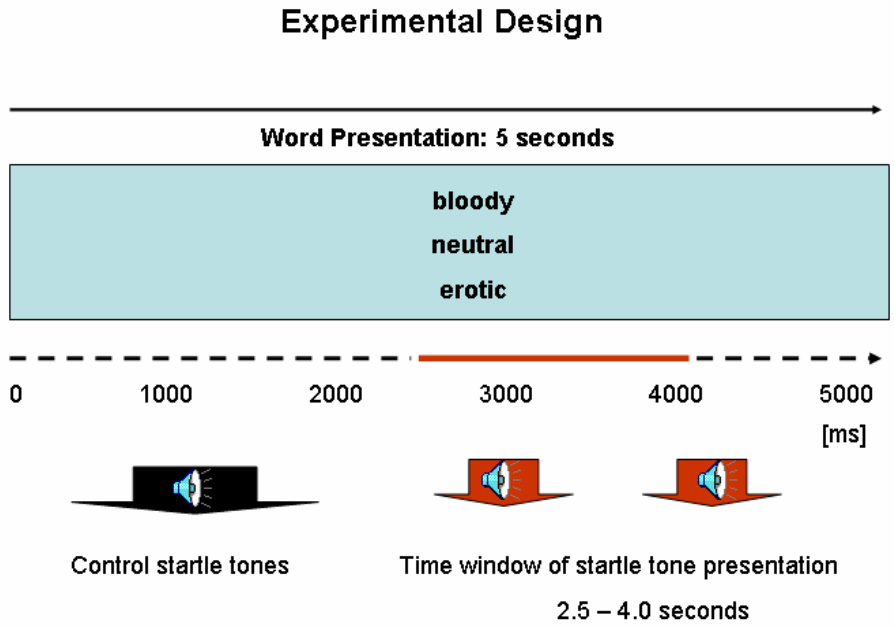
2.3. Experimental Design

Adjectives were presented for 5 s in black letters centred on a white computer screen with an interstimulus interval (ISI) of 1000 ms. Presentation order was randomized across emotional categories and subjects. For each subject, a startle tone occurred at a random time point, 2500 – 4000 ms after word onset during 20 of the words from each valence category, resulting in a 33% probability of startle tone occurrence. The assignment of startle tones to the words was randomly determined and individually different for each subject. One startle tone per word category occurred at 0 – 300 ms and one at 4700 – 5000 ms after word onset to reduce the predictability of startle tone presentation. These six trials were excluded from further analyses.

The acoustic startle stimuli consisted of 90-dB sound pressure level bursts of white noise with 50 ms duration and instantaneous rise and fall times. Startle probes were presented binaurally through stereo headphones. To avoid baseline shifts in muscle or central nervous system activity, word sequence was controlled such that startled words were never consecutive. In addition, no more than two words from a category occurred in sequence and presentation sequence of words from different word categories shared convergence in probability. Word sequence and startle

tone presentation were balanced across valence categories and across subjects. Experimental runs were generated and controlled by "Presentation" software (Neurobehavioral Systems, Inc.). A schematic overview of the experimental design is displayed in Figure 1.

Figure 1: *Experimental design of startle tone presentation during viewing emotional adjectives.*



2.4. Procedure

Subjects were familiarized with the laboratory setting, the experiment was explained to them in general terms, they were questioned with regard to their medical status, their handedness was determined, and they signed an informed consent form. Thereafter, electroencephalographic (EEG) and EMG electrodes were attached, and participants were familiarized with the experimental instructions. The instructions were designed to enhance active processing of the presented stimuli: Participants were told that emotional adjectives would be presented for 5 s each and that they should covertly evaluate their emotional meaning, that is, whether they regarded a word as emotionally unpleasant, pleasant, or neutral, and try to memorize them for a subsequent test. They were also told to ignore all of the randomly occurring loud tones, played through headphones. Subjects were instructed to keep their eyes open and fixate on the center of the screen for the entire time of word presentation.

2.5. Physiological Data Collection and Reduction

EMG and EEG data were recorded using a NEUROSCAN SynAmps amplifier and software.

2.5.1. Electromyographic recording

The eyeblink component of the startle reflex was recorded electromyographically from the orbicularis oculi muscle beneath the left and right eyes, using miniature Ag/AgCl electrodes (5 mm in diameter). The electrodes were placed 1 cm apart beneath both eyes. Interelectrode distance was kept constant for both eyes and all subjects.

The continuously recorded EMG signal was collected with a bandpass from DC to 500 Hz, amplified by 500 and sampled at 2000 Hz. EMG electrode impedance was held beneath 5 kΩ. Off-line, the digital EMG signal was bandpass filtered at 28 – 500 Hz and rectified. Startle blinks were measured off-line from 100 ms before until 300 ms after the onset of each startle probe scoring onset latency in milliseconds and peaks in microvolts for each trial and word category. Startle segments were baseline corrected using the interval before onset of the visual stimulus from 100 ms before until word onset.

Exclusion criteria for baseline corrected peak and latency scoring were a response onset before 20 ms or a response peak later than 200 ms after probe onset, as well as an onset-to-peak latency greater than 120 ms. Additionally, as subjects were not adapted to startle tones before the experiment, the first recorded blink of each word category and subject was rejected from further analysis. For each subject, EMG eyeblink amplitude averages were computed for the individual emotional word categories. Latency of startle peaks was measured, but no valence effects were detected and thus latency is not further reported here. Recording and analysis of startle data followed recommendations by Berg and Balaban (1999), and Blumenthal et al. (2005).

2.5.2. Electroencephalographic recording

The EEG was recorded from 64 channels, using an EasyCap system. Raw EEG data were collected with a bandpass from DC to 500 Hz, sampled at 2000 Hz, and down-sampled off-line to 256 Hz. All EEG channels were recorded against a Vertex reference (Cz) and converted off-line to an average reference. For all electrodes, recording impedance was held beneath 5 kΩ. Filtering, artifact rejection, and analyses of the ERP responses followed off-line: Data were filtered from 0.53 to 30 Hz.[4] Filtered data were corrected for eye movement artifacts using the

[4] Some studies investigating P3 and LPC components have used lower high-pass filters than those chosen in the current study (e.g., 0.1 Hz or 0.03 Hz). While this may affect the general morphology of the late components, it will not annihilate experimental effects (e.g., Duncan-Johnson & Donchin, 1979). Specifically, differences in late components observed with a higher high-pass filter will not vanish with a lower filter setting, although the converse may be true. Thus, a higher filter setting, like the one used here, will result in a more conservative estimation of the experimental differences. For visualization of effects, VEP effects are presented in Figure 3, using filter settings of 0.1-30 Hz.

ocular correction algorithm of Ille, Berg, and Scherg (2000). In addition a semiautomatic artifact rejection as implemented in BESA (MEGIS Software GmbH) was run to eliminate remaining artifacts. Artifact-free EEG data were segmented from 100 ms before word onset until 4000 ms after word onset and baseline corrected using the 100 ms before word onset as a baseline for both the visually and the auditory evoked potentials.

A. Visually evoked potentials

For each subject, visually evoked ERP components for startled words were averaged for each word category separately: The N1, P2, P3, and LPP components were scored by determining the mean activity on averaged waveforms for each subject, valence category, and sensor. N1 was determined within a time window starting from 50 ms to 180 ms after word onset. P2 was determined using the time window from 180 ms until 250 ms after word onset and P3 amplitudes were analyzed from 250 ms until 400 ms after word onset. The visually evoked LPP complex was scored from 600 ms to 750 ms after word onset.

The N1 component was determined at a group of parieto-occipital electrodes including PO3, PO4, P1, P2, Pz, O1, O2, O9, O10, and Oz. The P2, P3, and LPP visual components were scored at a group comprising P1, P2, P5, P7, C5, C4, Pz, Cz, CP5, CP4, and CPz. The averaged activities from these groups of electrodes were, for each component individually, entered into the statistical analysis to get a topographically stable estimate of the underlying brain activity without inflating the likelihood of type I errors.

B. Auditory evoked potentials

The acoustically elicited N1 and P3 components of the startle tones were determined for each word category and subject. The N1 was determined as the mean activity within a time window from 80 ms to 180 ms after startle tone presentation for each subject, valence category, and sensor. The startle P3 amplitude was analyzed within 280 ms to 380 ms after startle tone onset. P3 latency was also measured, but no effects of valence on latency were observed.

The startle tone N1 as well as the startle tone P3 waveforms were statistically tested at the following group of electrodes: FCz, Cz, CPz, Pz, FC1, FC2, C3, C4, CP1, CP2, CP3, CP4, P1, and P2. Statistical analysis for both the N1 and the P3 startle tone amplitudes is reported for the averaged activity from this group of electrodes.

3. Statistical Data Analysis

3.1. Startle eyeblink

To examine affective modulation of the startle reflex during word processing, blink amplitude was analyzed in a repeated measures analysis of variance (ANOVA), involving the factors 'Valence' (pleasant, unpleasant, and neutral) and 'Eye' (left, right) as within-subject factors. Post hoc planned comparisons were used to compare the three affective categories.

3.2. ERPs

To test basic effects of emotional word processing on visually evoked potentials and auditory startle P3 modulation, a one-way repeated measures ANOVA was calculated containing the variable 'Valence' (pleasant, unpleasant, and neutral word categories) as repeated measures. Based on representative ERP topographies valence effects were statistically tested at averages of the electrode groups described above. For significant main effects post hoc analyses for ERP amplitudes were performed, using planned comparison tests.

Significance levels for EMG and ERP data are reported after adjustment for violations of the sphericity assumption using the Huynh–Feldt procedure, where warranted.

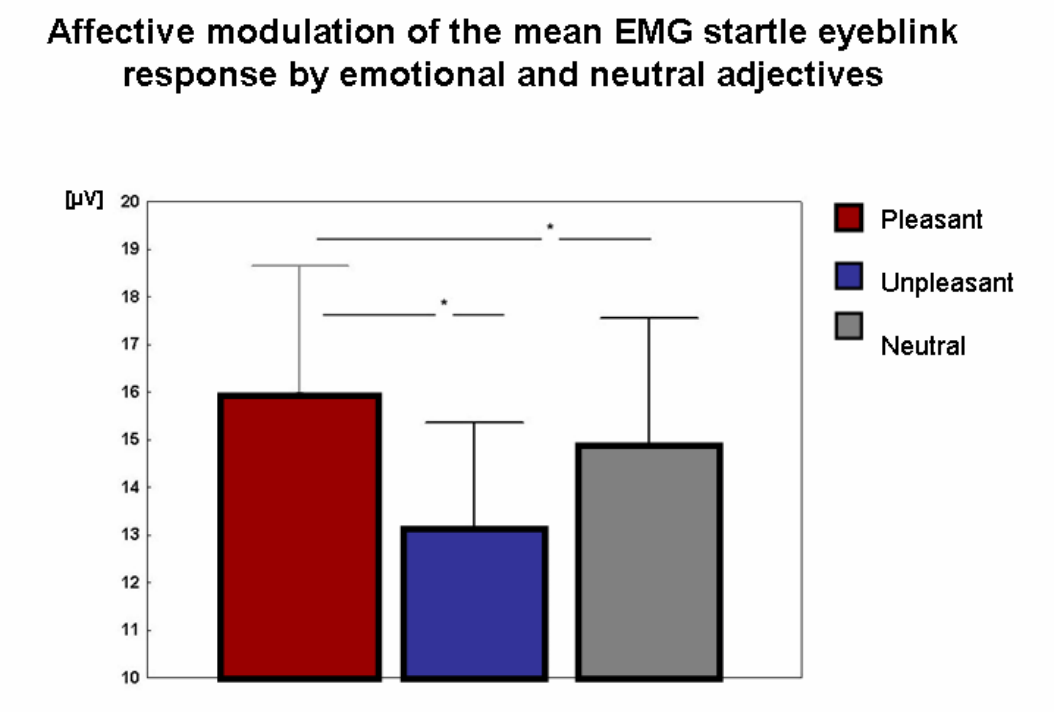
4. Results

4.1. Startle Eyeblink

The peak amplitude of the EMG startle eyeblink component varied with word category ('Valence': $F(2,50) = 8.98$, $p < .005$). Follow up analyses revealed that peak amplitude of the eye blink was larger when pleasant words than neutral words (pleasant > neutral: $F(1,25) = 4.5$, $p < .05$) or unpleasant words (pleasant > unpleasant: $F(1,25) = 11.8$, $p < .005$) were viewed. No significant effect for the main factor 'Eye' was obtained ('Eye': $F(1,25) = 0.88$, $p > .36$). Affective blink facilitation for pleasant words was found for both eyes and did not differ between left or right recording sites ('Valence × Eye': $F(2,50) = 2.4$, $p_{Huynh\text{-}Feldt} > .09$ (Huynh-Feldt epsilon = 1.0)).

Results of affective eyeblink modulation are shown in Figure 2.

Figure 2: *EMG mean startle eyeblink amplitudes during viewing pleasant, unpleasant, and neutral adjectives. For illustration EMG mean startle eyeblink responses were averaged across the left and the right eye.*



4.2. Auditory Startle Evoked Potentials

4.2.1. Auditory N1

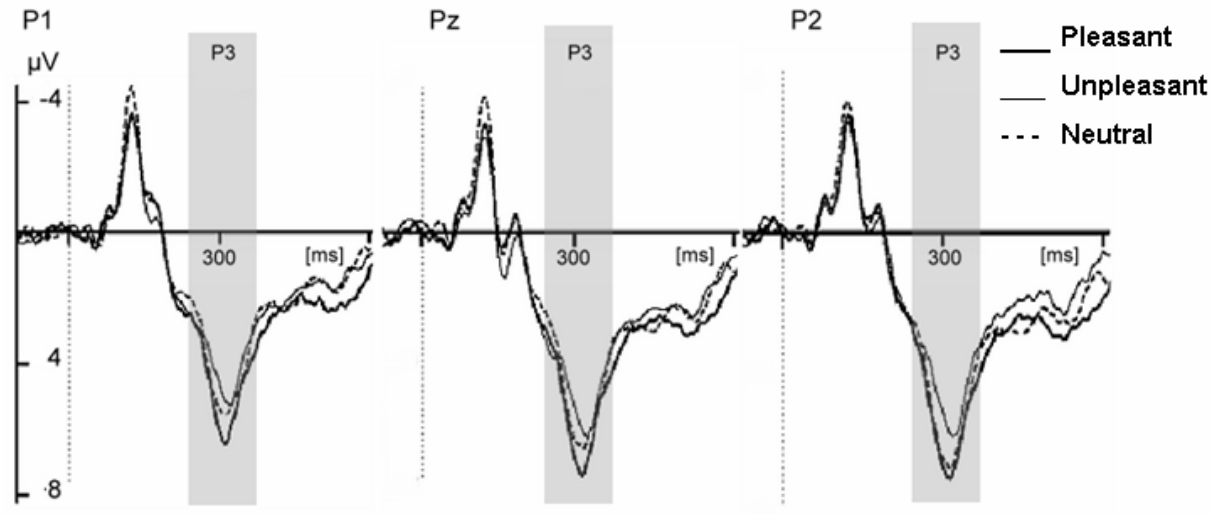
The acoustically elicited startle tone N1 amplitude did not vary significantly with stimulus valence, indicating that the startle tones at this early stage were equally processed, regardless of whether the foregrounds were emotional or neutral in meaning ('Valence': $F(2,50) = .97$, $p > .39$).

4.2.2. Auditory P3

The valence of the foreground words affected the auditory P3 response ('Valence': $F(2,50) = 4.7$, $p < .01$). Startle P3 amplitude was more pronounced for pleasant words in comparison to neutral (pleasant > neutral: $F(1,25) = 5.6$, $p < .05$) and unpleasant words (pleasant > unpleasant: $F(1,25) = 10.9$, $p < .01$).

Grand average waveforms of the auditory cortical brain potentials elicited by the startle tone during processing of pleasant, unpleasant, and neutral adjectives are presented in Figure 3 for three parietal electrode sites.

Figure 3: *Effects of startle P3 modulation during viewing pleasant, unpleasant, and neutral adjectives at three parietal electrodes.*



4.3. Visually Evoked Potentials

4.3.1. Visual N1

As in the analyses of the auditory evoked N1, the acoustically elicited startle tone N1 amplitude did not vary significantly with stimulus valence, indicating that all words, regardless of their emotional meaning, were initially responded to in a similar manner ('Valence': ($F(2,50) = 1.4$, $p > .26$).

4.3.2. Visual P2

In contrast to non-significant results for the N1 amplitude, the visual P2 potential was significantly more pronounced for both unpleasant and pleasant relative to neutral adjectives as indicated by post-hoc comparisons of the significant main effect of Valence ('Valence': $F(2, 50) = 5.1$, $p < .01$; pleasant > neutral: $F(1, 25) = 6.8$, $p < .05$; unpleasant > neutral: $F(1, 25) = 7.5$, $p < .05$).

4.3.3. Visual P3

Processing of positively and negatively valenced adjectives elicited significantly larger P3 potentials of the visually evoked brain potential than processing of neutral adjectives ('Valence': $F(2, 50) = 3.3$, $p < .05$). Regardless of valence, emotional words drew more attention than neutral ones (pleasant > neutral: $F(1, 25) = 3.5$, $p < .07$; unpleasant > neutral: $F(1, 25) = 4.9$, $p < .05$).

4.3.4. LPP component

Emotional valence of the presented words also affected the visual LPP ('Valence': $F(2, 50) = 4.9$, $p < .01$). In contrast to larger P2 and P3 modulation for both unpleasant and pleasant adjectives, post hoc comparisons revealed that processing pleasant words produced significantly larger amplitudes of the LPP compared to unpleasant and neutral ones (pleasant > neutral: $F(1, 25) = 7.2$, $p < .01$; pleasant > unpleasant: $F(1, 25) = 5.7$, $p < .05$). Larger LPP activity for pleasant adjectives than for both neutral and unpleasant adjectives might signal that subjects were more engrossed in evaluative encoding of pleasant words.

The time course of the ERPs recorded during processing pleasant, unpleasant, and neutral words is shown in Figure 4a together with topographic difference maps of significant emotion effects (Figure 4b).

Figure 4: *VEP emotion effects*

Figure 4a: *Visual event-related potentials during viewing pleasant, unpleasant, and neutral adjectives at central, centro-parietal, parietal and occipital electrodes. Filter 0.1-30 Hz.*

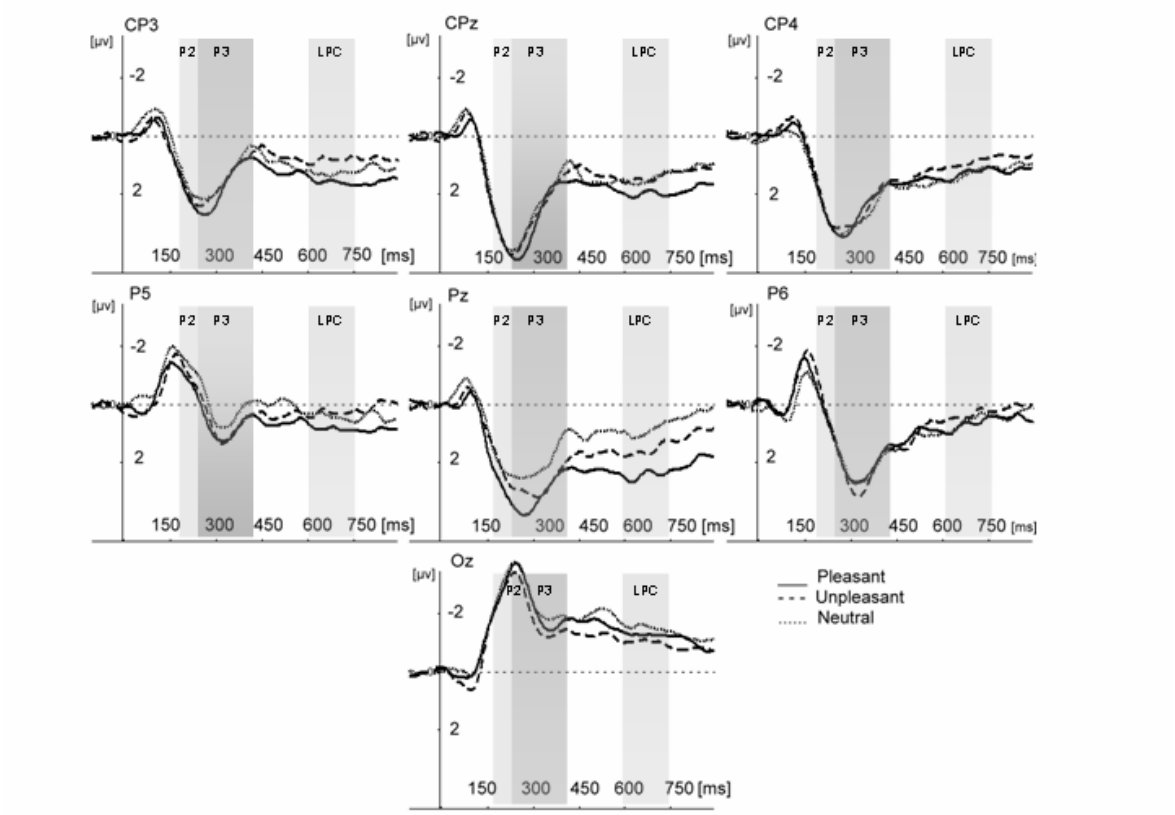
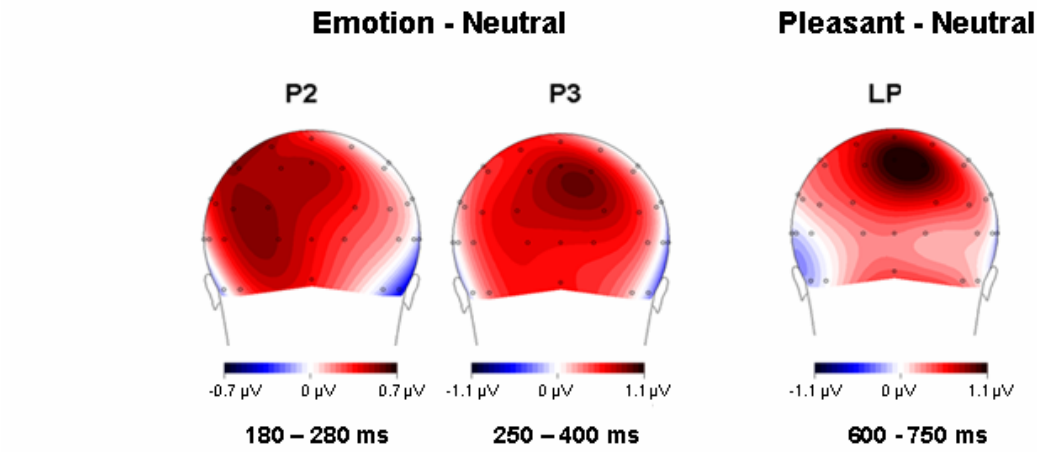


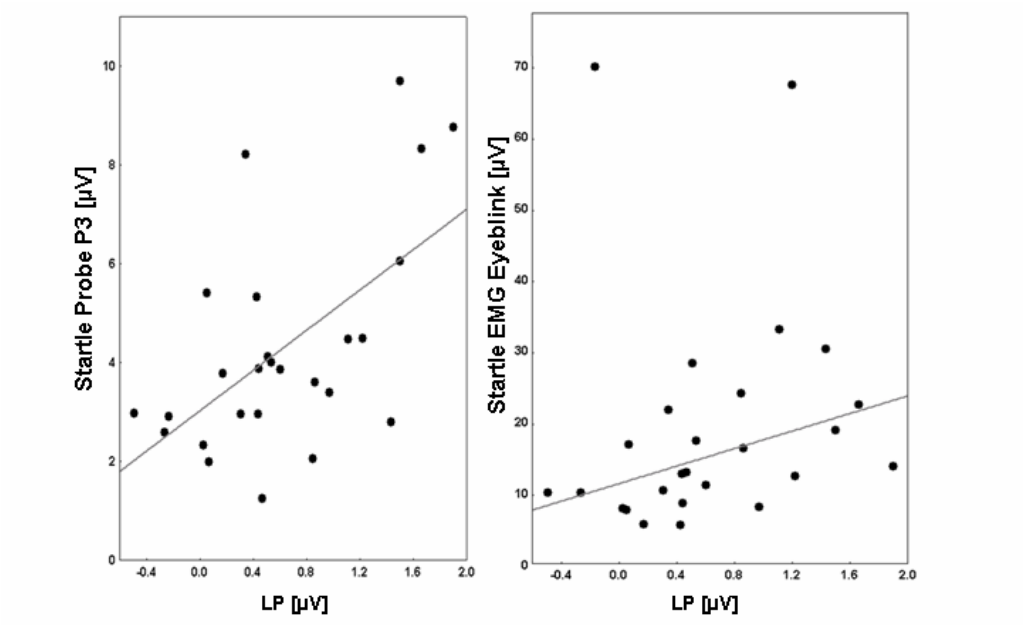
Figure 4b: *Topographic difference maps of significant emotion effects*



4.4. Correlation Analysis

For pleasant foregrounds, a parallel between increased LPP amplitudes and the startle tone P3 brain potential as well as the EMG startle eyeblink response was observed. To explore whether this relationship could be statistically confirmed, correlations were calculated to quantify the strength of this association for each emotion category individually.
Figure 5 displays the significant correlations obtained between cortical positivity (LPP) and startle reactivity during viewing pleasant adjectives.

Figure 5: *Regression plots obtained for cortical positivity (LPP analysis) and startle reactivity during processing of pleasant adjectives. The left panel shows LPP amplitude plotted against auditory startle P3 amplitudes. The right panel shows LPP amplitude plotted against EMG startle amplitude. Two subjects produced remarkably large startle responses (Figure 5, right panel). These outliers were excluded from the EMG correlation analysis and also all other analyses were recalculated without these su*bjects. *This affected neither the direction nor the significance levels of the results.*



For pleasant adjectives, significant correlations (Pearson's *r*) were observed between the LPP activity and the magnitude of the auditory startle P3 amplitude, $r = .57$, $p < .01$, as well as the LPP activity and the magnitude of the startle eyeblink response, $r = .47$, $p < .05$. No significant correlations were found for either the neutral or unpleasant stimuli, all ps >.1. Of note, there was no significant correlation between visual P3 amplitude and any measure of startle reactivity for any valence category, all p >.1.

These results support the view that sustained processing of pleasant adjectives is an important factor for the increased startle reactivity found when subjects were engaged in the processing of words with pleasant rather than unpleasant or neutral meaning.

5. Discussion

The current study examined the extent to which affective startle reflex modulation occurs when people evaluate visually presented emotional adjectives, measuring the EMG eyeblink component and the auditory evoked probe P3 of the startle tone. Additionally, the processing of the affective foregrounds was examined through analysis of the visually evoked cortical potentials. The relationship between cortical processing of the foreground stimuli and cortical (probe P3) as well EMG indices of startle reactivity was quantified by correlation analyses.
The verbal emotional foreground had a significant impact on both the peripheral and the central nervous physiological measures of the startle response. Both startle EMG amplitude and auditory evoked P3 amplitude were larger for pleasant than for neutral and unpleasant verbal foregrounds. Differential processing of the emotional adjectives could be ascertained through analysis of the visually evoked potentials elicited during word processing. In the P2 and P3 time windows, both pleasant and unpleasant adjectives were associated with larger positivities than neutral words, indicating the allocation of more resources to emotional adjectives, regardless of valence. Further elaboration (as reflected in the late positive component) was only present during processing of pleasant words and was correlated with EMG and auditory P3 responses to the startle tone.

5.1. Time course of emotional word processing

A pronounced P2 component when reading emotional words has been reported in many EEG studies during emotional word processing and has been interpreted as an index of enhanced stimulus discrimination for emotional in comparison to neutral words (e.g., Bernat et al., 2001; Pauli et al., 2005; Shapkin et al., 2000). An enlargement of the visually evoked P3 potential to emotional compared to neutral adjectives, regardless of processing task (structural vs. affective), was reported by Naumann and colleagues (1992) and suggests facilitated attentive processing of emotional in contrast to neutral adjectives.
In the late positive component time window, evoked responses to pleasant adjectives continued to be amplified whereas brain responses to unpleasant and neutral words did not differ any

longer. Larger late positive components during emotional word processing have been reported in a number of previous studies (e.g., Knost et al., 1997; Naumann et al., 1992; Williamson et al., 1991) as an index of enhanced elaborative processing (e.g., Paller, Kutas, & McIsaac, 1995). Thus, in the present study both pleasant and unpleasant adjectives were discriminated better from neutral ones and received more attention than neutral words, but pleasant adjectives only were further elaborated.

5.2. Affective modulation of the startle reflex

Startle potentiation with unpleasant linguistic emotional foregrounds has been reported to occur at very short lead intervals (e.g., Aitken et al., 1999; Knost et al., 1997; Waters et al., 2000). However, both the present data and previous results show that when the startle tone is presented at later SOAs different patterns are obtained: Here, as in the studies of Aitken et al. (1999) and Waters et al. (2000), no modulation of the startle eyeblink by unpleasant verbal foregrounds at lead intervals ≥ 2000 ms was found. Unfortunately, neither of the previous studies has assessed responses to pleasant foregrounds or used central nervous indices of lead and startle stimulus processing. Knost and colleagues (1997) has also focused on unpleasant lead words at extremely short lead intervals (1.25 ms after word onset) but assessed visually evoked brain responses to the lead stimuli. The study found both enhanced startle EMG and larger late positive potentials (LPP) to the emotional, albeit unpleasant, than to the neutral words. A parallel between the cortical processing stage and startle amplitude is also reported by Baas, Kenemans, Böcker, and Verbaten (2002), who reported larger startle responses and a pronounced protracted parietal positivity for simple grating stimuli that served as forewarning signals of an imminent shock. The parallel between EMG response patterns and the late positive component across studies suggests a relationship between the processing stage of the foreground stimulus and the size and direction of the startle response.

Previous text imagery research suggests that startle reactivity covaries with the depth of internal cognitive processing (e.g., Miller et al., 2002; Panayiotou et al., 1998). According to these authors, startle reactivity is influenced by the degree of internal processing or active disengagement from the sensory environment. It is assumed that when people are actively engaged in internal processing, a startle tone serves as an alerting stimulus, and the EMG startle response is facilitated regardless of stimulus valence (e.g., Miller et al., 2002). The current study supports this thesis by finding significant correlations between LPP magnitude for pleasant adjectives and both EMG and ERP measures of startle. Instructing subjects to evaluate the

emotional meaning of the presented adjectives and to memorize them should direct subjects' cognitive resources away from perceptual processing of the presented words and increase mental load on internal processes. Under such circumstances, in accordance with Miller et al. (2002), the current findings suggest that evaluative word viewing, like text-prompted imagery, incorporates aspects of a "cognitive-mentational task" that relies on elaborative internal processing and involves active disengagement from sensory input. The visually evoked potential tracings in response to the word stimuli clearly demonstrate that, at least during later stages of processing, subjects were more engrossed in processing of the pleasant than of the neutral or unpleasant materials. Thus, a larger processing interrupt effect will result for the pleasant adjectives leading to larger EMG blink responses.

When startle tones occurred during pleasant adjectives, the auditory startle P3 response to the tone was likewise enlarged in comparison to unpleasant and neutral words. At first glance, this may appear surprising in view of findings of reduced probe P3 coinciding with facilitated EMG startle (e.g., Cuthbert et al., 2000; Schupp et al., 1997), which have been accounted for in terms of resource competition. However, so far no study has directly investigated auditory startle probe P3 under conditions of interrupted internal mental engagement. In fact, it is reasonable to assume that when subjects are suddenly re-alerted from mental engagement to their physical environment this "call to arms" will be associated with enhanced processing of all aspects of the alerting stimulus, including heightened alertness to the stimulus and response preparation (e.g., Graham, 1979; Lacey, 1967). Graham first suggested that the startle response provides a protective function by interrupting internally focused processes and mobilizing the organism to respond to significant changes in the environment. Like Graham and Miller and colleagues (2002) note that ‘without such an interrupt mechanism, non-perceptual processing would leave the organism highly vulnerable to environmental threat’ (pp. 527).

Electrophysiologically, the current results demonstrate that this interruptive call to arms results in enhanced amplitudes of the auditory startle P3. Generally, P3 is assumed to be related to attention (e.g., Donchin et al., 1988; Verleger, 1988), but it can also be elicited by salient stimuli such as loud noises when no task is assigned (e.g., Ford, Roth, & Kopell, 1976). Ford and Roth (1999), on the basis of pilot data, assumed that like blink facilitation, startle P3 amplitude should be enhanced as a consequence of successful re-alerting to salient startling tones, especially after long lead intervals. Our results corroborate the interpretation of increased startle eyeblink responses and startle P3 as a consequence of successful processing interrupt, both via the LPP indices of mental engagement and the correlation of LPP magnitude with both EMG startle eyeblink and auditory startle P3 amplitude during processing of pleasant adjectives.

The question remains as to why particularly the pleasant adjectives were subject to more processing than the other two emotional categories. The pleasant and unpleasant adjectives used in this study were both highly arousing and did not differ in emotional arousal according to normative student ratings. Both emotional categories preferentially drew subjects' initial attention as evidenced by the visual ERP effects at P2 and P3 for both pleasant and unpleasant adjectives. However, the unpleasant stimuli did not show a heightened late positive component and did not affect the startle reflex. This may be due to asymmetries in emotional processing caused by specifically three influential factors related to individual differences in affect, the amount of physiological arousal elicited by emotionally verbal stimuli, and task demands. Also a combination of these three variables is reasonable. Concerning individual differences in affect, startle potentiation to unpleasant stimuli has been observed to be largest in various clinical populations for particularly threatening and disorder-related stimuli (e.g., Aitken et al., 1999; Knost et al., 1997; Lang, 1995; Waters et al., 2000). Alternatively, healthy subjects often show a processing bias for pleasant material that is associated with larger late cortical potentials, stronger limbic system activation and better memory encoding for pleasant than unpleasant words (e.g., Canli et al., 2004; Hamann et al., 2002; Kiefer et al., in press). This pleasure bias has been considered to result from a generally stronger pronunciation of 'positive affect' than 'negative affect 'in healthy subjects (e.g., Diener et al., 1996) and may be apparent in the current study showing that subjects tended to elaborate pleasant adjectives more deeply than unpleasant or neutral words as indicated by enhanced amplitudes of the LPP for pleasant adjectives. Concerning stimulus arousal, a 'positivity offset' is often found at low and moderate levels of arousal in that the approach system responds more strongly to relatively little input. The withdrawal system in response to unpleasant input, in turn, is activated comparatively more at high levels of arousal, this latter process being termed 'negativity bias' (e.g., Cacioppo, 2004; Ito & Cacioppo, 2000). In picture viewing studies with long lead intervals, the classic finding of startle potentiation for unpleasant and startle inhibition for pleasant material is only observed at the highest arousal levels, whereas at medium or low levels of arousal, the pattern is more variable or can even be reversed (Cuthbert et al., 1996). It is reasonable to assume that visually presented words generally constitute less arousing stimuli than complex coloured pictures, that is, the word *cruel* will be less arousing than a photograph of a corresponding scene, even if both stimuli receive comparable ratings.[5] Therefore, in the absence of strong personal associations for unpleasant words - which may have been present in various clinical populations that have

[5] The SAM rating scales hold only within a given set of stimulus materials and do not represent absolute values of a given attribute. Hence, a rating value of nine on an arousal scale for pictures cannot be equated with the same value for other materials such as words.

previously been studied - a 'positivity offset' for written verbal material can be expected in healthy subjects displaying stronger personal associations for pleasant words. Recent neuroscientific studies support this reasoning. Hamann and Mao (2002) report that when healthy subjects explicitly evaluate verbal stimuli, unpleasant as well as pleasant nouns elicit activity in the left amygdala, but only pleasant nouns additionally activate dorsal and ventral striatal regions related to reward and positive affect, involving caudate, putamen, globus pallidus, and nucleus accumbens. All the foregoing brain regions have been found to modulate the startle circuitry (e.g., Skolnick & Davidson, 2002). Stronger amygdala activation for pleasant than unpleasant words in healthy than depressed subjects has also been reported by Canli and colleagues (2004) during a lexical decision task and Fossati and colleagues (2003) found stronger brain activation for pleasant than for unpleasant words in the insula, superior temporal, and parietal brain regions while healthy subjects evaluated emotional adjectives in relation to themselves. Electrocortical evidence for a sustained processing of pleasant adjectives has been reported by Kiefer and colleagues (in press), who found enhanced N400 and LPP components during encoding of pleasant in contrast to unpleasant adjectives. A bias in favour of pleasant words is also found in categorization paradigms: Reaction time advantages for pleasant material have repeatedly been reported for the emotional categorization of words and faces (e.g., Feyereisen, Malet, & Martin, 1986; Hugdahl, Iversen, & Johnson, 1993; Kiehl et al., 1999a; Lehr, Bergum, & Standing, 1966; Leppänen et al., 2003, 2004; Osgood & Hoosain, 1983; Stenberg, Wiking, & Dahl, 1998). These results underscore an important role of the task and processing stage in the emergence of pleasant–unpleasant asymmetries. Whereas early stimulus registration may be largely arousal driven or even prioritize highly arousing unpleasant stimuli (e.g., Dijksterhuis & Aarts, 2003; Morris et al., 1999; Öhman et al., 2001c) pleasant words enjoy an advantage in evaluation and categorical decision (e.g., Leppänen et al., 2004, 2005).

6. Conclusion

In the present study, ERP indices of foreground and startle tone processing as well as EMG startle responses were examined with both pleasant and unpleasant adjectives as affective foregrounds. Prolonged cortical processing as evidenced by the late positive component, enhanced auditory probe P3 responses, and startle potentiation were found for pleasant in comparison to neutral and unpleasant adjectives. Larger late positive components for pleasant adjectives statistically predicted more pronounced startle reactivity both, in the EEG and in the EMG. The data suggest that this relationship between emotional stimulus processing and

defensive reflex modulation will hold in tasks that require elaborative internal processing. In these contexts the startle tone will re-alert the subject to the environment, thereby amplifying various aspects of startle stimulus evaluation. The particular finding of enhanced elaboration of the pleasant stimuli may be attributable to individual differences in affect and a 'positivity offset' that occurs at lower levels of arousal and in stimulus categorization tasks.

VI. General Discussion
Conclusions, Perspectives and Implications

The purpose of the present thesis was to provide systematic research on the selective processing of emotional words. Basic research questions concerned the impact of processing of emotional meaning on word perception, attention, memory and the modulation of natural defensive responses. These questions were addressed systematically in four coordinated experiments by means of EEG (ERP) and functional imaging methods as well as peripheral and behavioural measures. Theoretically, the present thesis was based primarily on assumptions derived from the bio-informational theory of emotion and related empirical findings. The theory, previous empirical results with emotional pictures and words and their implications for the current experiments have been presented in detail in the general introduction and throughout this work.
The conducted experiments yielded several important findings that have been discussed thoroughly in each chapter with respect to theoretical and empirical considerations. The major findings will now be summarized. It will be shown that altogether, the reported findings provide strong evidence for the view that emotional word processing is biased in healthy subjects depending on the word's motivational significance, its arousal level as well as attentional demands and subjects' current motivational states and intentions. Additionally, conclusions that can be drawn from this bias in emotional processing will be outlined and discussed in consideration of theoretical assumptions and future perspectives for the study of emotional word processing.

In the first study described in chapter 1 (study 1), evaluative ratings of valence and arousal were assessed for a set of 486 German adjectives in a sample of students of the University of Konstanz. German language provides many adjectives that address qualitatively distinct emotional and neutral categories. Nevertheless, as predicted from the bio-informational theory, the adjectives clustered in a typical, u-shaped manner within a two-dimensional affective space, defined by the normative student ratings of valence and arousal. The affective space displayed important characteristic features that have been reported previously for subjective ratings of IAPS pictures and English words (e.g., Bradley, 1999b, Lang et al., 1997b) Firstly, adjectives rated as highly pleasant and unpleasant were also rated as highly arousing. This was particularly the case for adjectives whose meaning signalled strong appetitive or defensive motivational engagement of love, sex, thrill, threat or crime. By contrast, adjectives describing neutral attributes of people and objects (e.g., civilian, neutral, normal, artificial, etc.) were generally

rated as less arousing. Secondly, the covariation between arousal and valence was strongest for unpleasant adjectives. Pleasant adjectives were rated as either arousing or calm. However, there were no unpleasant adjectives that would have been judged as comparatively low in emotional arousal as pleasant adjectives. The pattern is consistent with findings reported for IAPS pictures and English words (e.g., Ito et al., 1998b) and supports the notion that emotional processing is biased in favour of a stronger engagement of the defensive system at extremely high levels of arousal (*'negativity bias'*) and a stronger activation of approach (*'positivity offset'*) at lower levels of arousal (e.g., Cacioppo, 2004).

Processing differences between highly arousing pleasant and unpleasant adjectives and highly arousing emotional and low arousing neutral adjectives were also found in the EEG (ERP) experiments described in chapter 2 (study 2) and 4 (study 4) as well as in the fMRI experiment described in chapter 3 (study 3).

The two EEG (ERP) experiments conducted in this work demonstrated that the time course of emotional word processing is variable. In both experiments it was found that stimulus arousal as well as stimulus valence modulated the selective processing of words differently across processing time and processing speed. At early processing levels, emotional arousal facilitated the selective processing of emotional meaning. When processing load increased, processing of unpleasant adjectives was most pronounced indicating that dangerous contents instantaneously obtain priority in processing. By contrast, a stronger preference for pleasant adjectives appeared to guide selective processing at successive stages of word perception bolstering semantic integration of pleasant information and its consolidation in memory. In the fMRI experiment described in chapter 3 this overall stronger relevance of arousing pleasant information, elicited in the first 1000 ms, was associated with enhanced brain activation in the ventral and dorsal visual processing stream, prefrontal motor areas and limbic structures such as the amygdala. However, the EEG-EMG study described in chapter 4 (study 4) showed that for the purpose of dealing adaptively with potential environmental danger, sustained mental elaboration of pleasant contents was interrupted as soon as an aversive sensory event such as a startling tone required rapid re-orienting toward the environment.

<u>Early selection effects of emotional word processing</u>

In the EEG (ERP) experiment described in chapter 2 (study 2) emotional and neutral adjectives were presented randomly in rapid streams (RSVP). Words had to be viewed passively.

Attentional processing load was modulated by presenting words with two different processing speeds (333 ms and 1000 ms). At early levels of stimulus perception, adjectives elicited an early posterior negativity potential, peaking over temporo-occipito and parieto-occipital electrodes at about 200 - 280 ms after word onset. Language and emotion research using emotional pictures have reliably and repeatedly shown that early posterior negativity potentials ("EPN") reflect early semantic and emotional stimulus categorization processes in the visual cortex (e.g., Hinojosa et al., 2000; 2001; Junghöfer et al., 2001; Martin-Loeches et al., 2001; Schupp et al., 2003a, b, 2004b). For emotional adjectives the brain potential was significantly enhanced in contrast to neutral adjectives. In addition, the amplitudes of the "EPN" increased significantly for emotionally unpleasant adjectives at faster processing speeds. The stronger impact of unpleasant adjectives is well in accord with reports of a stronger attentional bias for unpleasant emotional stimuli than for pleasant ones (e.g., Dijksterhuis et al., 2003; Hansen et al., 1988; Öhman et al., 2001c; Pratto et al., 1991; Smith et al., 2003, 2006) when processing load is high and perceptual awareness is limited (e.g., Anderson, 2005; Anderson et al., 2001; Smith et al., 2006).

The "EPN" potential results show for the first time, that highly arousing emotional adjectives akin to highly arousing emotional pictures capture attention rapidly and spontaneously, that is, without a viewer's explicit intention to attend (e.g., Junghöfer et al., 2001). Moreover, as has been reported for emotional pictures, emotion effects were not attenuated by stimulus repetition (Schupp et al., 2006b), underscoring the relevance of emotional stimuli in natural selective attention. Additionally, the findings suggest that this type of enhanced stimulus-driven attention for emotionally relevant words relies on a rapid extraction and activation of meaning rather than on the analysis of specific physical or lexical stimulus characteristics of emotional words such as word form. Although words elicited a prominent P1 potential that is associated with perceptual and syntactic analysis of words (e.g., Sereno et al., 1998) the P1 potential did not differentiate between emotional and neutral adjectives. As reported for emotional pictures (Schupp et al., 2006a) the early posterior negativity potential was clearly the first ERP component reflecting the differential processing of emotional compared to neutral adjectives. Similarly, in the EEG experiment described in chapter 4 (study 4), emotional differentiation started in the time window of the P2 potential when adjectives were presented for 5000 ms and subjects were asked to covertly evaluate the words' emotional meaning. There was no earlier emotional differentiation in the EEG activity. These early processing effects are important and will be discussed in more detail later on.

Late selection effects of emotional word processing

The emotional guidance of attention also affected word processing at several postperceptual word processing stages. When adjectives were presented for 5000 ms (study 4), larger amplitudes of the centro-parietal P300 amplitude indicated that adjectives from both emotional categories were attended to better than neutral adjectives. However, in contrast to early selection effects observed for the "EPN" and P2 potential or the P300 potential word processing as indexed by the N400 and the LPP was driven exclusively by pleasant valence. When adjectives were presented passively (study 2) and at slower processing rates (1 Hz) attenuated amplitudes of the N400 potential for pleasant adjectives in contrast to unpleasant adjectives indicated that pleasant meaning was integrated more easily in the current context than unpleasant meaning across repeated word presentations. Moreover, larger amplitudes of late positive potentials in response to pleasant adjectives than to unpleasant and neutral adjectives were found. Again, emotion effects were not influenced by word repetition. The LPP modulation pattern suggests that subjects spontaneously and repeatedly devoted more processing resources to the processing of arousing words with pleasant connotations which facilitated the integration of pleasant adjectives in memory. Results obtained from a surprise free-recall task at the end of the experiment corroborated this interpretation, showing better memory for pleasant as compared to unpleasant and neutral adjectives.

The stronger advantage for pleasant adjectives than unpleasant ones at later processing stages agrees well with an extant literature on mood-congruent processing effects. This body of literature suggests that emotional processing is biased toward a preference for pleasant stimuli in healthy subjects (e.g., Diener et al., 1996; Ferré, 2003; Fredrickson et al., 2005; Isen, 2001; Kiefer, et al., in press; Zajonc, 2001). Specifying this "pleasure phenomenon" in more detail, the results presented here suggest that individual preferences for pleasant material dominate at later processing stages, where stimulus evaluation is thought to be goal-driven - either by task instructions or self-generated intentions (e.g., Yantis, 1998).

This assumption is also supported by previous EEG (ERP) studies (e.g., Kiefer et al., in press, Schirmer et al., 2005) and by the results of the EEG experiment described in chapter 4 (study 4), again showing stronger processing effects for pleasant adjectives at the time window of the LPP while healthy subjects covertly evaluated emotional and neutral adjectives.

Brain structures involved in the processing of emotional words

A stronger preference for pleasant adjectives was also confirmed in the fMRI experiment (study 3), underscoring the role of the amygdala in visual processing of highly arousing pleasant

material. In the fMRI study described in chapter 3, healthy student participants were asked to silently read a set of randomly presented emotionally arousing and low arousing neutral adjectives. Adjectives were presented event-related, for 1000 milliseconds.

Silent reading of emotional in contrast to neutral adjectives enhanced activation in visual and limbic as well as premotor cortex areas. However, additional analyses revealed that pleasant adjectives activated the left amygdala significantly and produced a more robust activation pattern in the left occipital and infero-temporal visual cortex than unpleasant and neutral adjectives. For pleasant adjectives visual cortex activation included brain areas of the entire left ventral visual processing stream such as primary and secondary sensory cortex areas as well as infero-temporal brain areas of the left fusiform gyrus. Processing of pleasant adjectives additionally led to an increase in left anterior parahippocampal regions and parietal and anterior temporal cortical brain structures involved in attention control and higher-order visual processing.

The neuroimaging results suggest that especially pleasant adjectives benefited from re-entrant processing between the amygdala and the ventral visual processing stream. The findings render obvious that pleasant adjectives were also selected for a more detailed attentive meaning encoding and response preparation. As observed in the RSVP-EEG study in chapter 2, pleasant adjectives were spontaneously better remembered than unpleasant and neutral adjectives. Better memory consolidation for pleasant adjectives may have in part been due to the overall stronger brain activation pattern in limbic and cortico-limbic higher-order visual processing areas of the anterior temporal pole. Recent imaging data showing stronger activation in the amygdala and in anterior parahippocampal regions as well as in anterior temporal brain areas during the processing of arousing emotional items which were remembered more correctly later speak in favour of this assumption (e.g., Dolcos et al., 2004). Of course this suggestion needs to be examined in more detail in future studies.

So far, the current imaging data show that emotional processing is biased toward a stronger preference for arousing pleasant material in healthy subjects and proposes that this bias involves the amygdala which is in accord with other imaging reports (e.g., Canli et al., 2001, 2002, 2004; Hamann et al., 2002). Furthermore the fMRI data is also in line with the cortical modulation pattern observed in the EEG (ERP) experiments presented in this work and during longer word exposures. In the two EEG experiments described in chapter 2 and 4 cortical activation remained enhanced for pleasant but not for unpleasant adjectives when adjectives were presented for 1000 ms (study 2) or longer (study 4). Methodologically, event-related fMRI designs are sensitive to detect small changes in regional cerebral blood flow (rCBF) with a reliable spatial resolution. However, the temporal resolution of functional activation is limited to the temporal

characteristics of the hemodynamic response function requiring at least 1 - 2 seconds before reaching its peak maximum. A long temporal resolution like this requires that activation remains elevated and stable over an extended period of stimulus time before activation differences can be reliably detected. The restriction of imaging methods in temporal resolution and the results from the EEG studies may explain why facilitation of pleasant adjectives in contrast to unpleasant adjectives was more pronounced in the fMRI experiment when adjectives are presented for 1000 ms. Using shorter stimulus durations (more rapidly presentation of word stimuli) may show if pleasant words are indeed more preferentially processed in the brain, particularly in the amygdale, than unpleasant words or vice versa. Regarding the current RSVP-EEG findings (study 2) with brief word presentations (333 ms), a stronger impact of both emotional word categories, especially of unpleasant adjectives, on amygdala-driven early visual processing may then be expected. This hypothesis should be tested in future imaging studies.

Modulation of the defensive startle reflex during emotional word processing

Also in the examination of the defensive startle-response there was an effect of valence with pleasant adjectives influencing the modulation of the startle responses. In the study described in chapter 4 (study 4) EEG (ERP) and EMG measures were combined to address the hypothesis of motivational/ emotional priming of the bio-informational theory. In contrast to the predictions of the motivational priming model and to previous findings with emotional pictures, different results were obtained. Analysis yielded larger blink potentiation and enhanced auditory startle probe P3 potentials during processing of pleasant adjectives while both startle measures were attenuated during viewing unpleasant or neutral adjectives. Analysis of visually evoked potentials (VEPs) revealed that blink potentiation was due to the fact, that, as found in the EEG study in chapter 2 (study 2) and already mentioned, participants processed pleasant adjectives more intensely than unpleasant or neutral adjectives. Despite of the fact that larger P2 and P3 potentials to emotional adjectives indicated that adjectives from both emotional categories were discriminated from neutral adjectives (P2 potential) and also better attended to than neutral adjectives (P3 potential), only pleasant adjectives amplified the LPP. Furthermore, the LPP correlated positively with startle probe P3 and blink responses. The correlation between the amplitudes of the LPP and both measures of the startle reflex (startle probe P3 and blink response) showed that the magnitude of simultaneously presented startle tones and startle reflexes covaried with the depth of processing elicited by emotionally pleasant adjectives. Thus, the modulation pattern of the VEPs suggests, that at the time startle tones were presented (2.5 – 4 seconds after word presentation), processing of emotional words had already shifted from active

sensory processing (e.g., P2 and P3 potential) toward a stronger mental processing (LPP) of the emotional meaning of words.

During mental processing which was palpably most pronounced for pleasant adjectives the defensive startle reflex may have served as a protective function of interrupting ongoing mental processing thereby allowing rapid re-orienting to potential environmental threat (e.g., Graham, 1979; Lang, 1995; Miller et al., 2002). This interpretation may not be conflicting with the motivational priming hypothesis. The motivational priming hypothesis makes no clear assumptions about startle reflex modulation during mental processing of emotional stimuli. In the motivational priming view, startle-responses are primed or inhibited conform to expectations as long as attention is oriented toward external sensory processing of unpleasant or pleasant stimuli and the organism is tuned to actively attend to and cope with those emotional stimuli (e.g., Lang et al., 1997a). For less concrete emotional foreground stimuli such as emotional words this attention capture may occur at earlier time points in the time window of the visually elicited P3 potential and startle tones presented earlier than 2.5 - 4 seconds after word presentation. However, during later time points of increased mental processing of emotionally pleasant words, the findings indicate that a strong primary sensory reinforcer such as a startling tone is likely to interrupt ongoing cognitive processing to release processing resources for a rapid re-orienting toward the environment. To date, this is the first study that investigated the modulation of the startle reflex by emotionally unpleasant and pleasant words and during later time points of word processing in healthy subjects. Thus, more empirical evidence is needed a) to confirm the current findings predicting startle potentiation during enhanced internal processing of emotional words and b) to elucidate where in the processing stream motivational priming of defensive reflexes by emotional verbal foregrounds may begin and be expected.

Altogether, the current results provide strong evidence for the view that emotional word processing is biased in healthy subjects with respect to the motivational significance and the arousal level of words. Whereas stimulus arousal and also negative valence ensure a rapid capture of attention at a perceptual processing level, semantic integration, word encoding and long-term memory processes are sustained for pleasant words. This overall stronger weighting of pleasant information involves limbic emotion structures and attests a preference for pleasant material in healthy subjects. Attentional demands of the task and individuals' current motivational states and intentions may all play a critical role for this bias in emotional processing. Moreover, in a natural viewing context, such as is the case in passive viewing tasks or covert evaluation tasks these pleasant-unpleasant processing asymmetries definitively occur

spontaneously. Thus, these asymmetries may indeed reflect a natural bias in emotional processing/evaluation, triggered by the defensive and appetitive motivational brain systems involving the amygdala and elicited by the language stimuli that we perceive and upon which we are reflecting.

Today, comparatively little is known about the cerebral processes associated with emotional word processing in healthy subjects. Particularly pleasant words and passive viewing conditions have rarely been examined. The current findings clearly show that the story told by pleasant words will be an important one. The experiments reported in this work examined the core assumptions of the bio-informational theory for the processing of emotional verbal stimuli. For emotional words similar multidimensional attempts with reference to the bio-informational theory are still lacking. Thus, the observed findings should be considered as a starting point for future investigations.

Future Perspectives

The current experiments provide several important and new insights in the selective processing of emotional words that deserve to be examined in future.

Specifically, the factors that contribute to the preference for pleasant stimuli – that has been so consistently observed in the current studies – are worthwhile being investigated in future in further detail. A closer examination of individual differences in affect may be interesting. To this end, assessment of personality traits and positive mood states of subjects, participating in the specific studies may be helpful. Additional insight may be derived from analysis of gender differences. Differences in valence ratings between men and women have been reported in previous studies using picture material (e.g., Bradley et al., 2000; Ito et al., 2005). While men appear more likely to report high valence-ratings for arousing adventure and sexual pictures, women prefer low arousing pleasant stimuli and experience and express more positive emotions than men (see Ito et al., 2005 for an overview). Additionally, women tend to report stronger unpleasant reactions to highly arousing threatening pictures to whom they also respond with greater physiological and defensive reactivity as measured by skin conductance or the startle blink reflex than men (e.g., Bradley, Codispoti, Sabatinelli, & Lang, 2001). In the present work the samples of participants were balanced for gender. Preliminary analysis of the current data not reported in this work did not reveal any stable gender differences in emotional word processing neither in the valence and arousal ratings assessed in the normative student sample (study 1) nor in any of the neural or peripheral measures. Larger participant samples may be necessary to

reveal gender-related differences in the processing of unpleasant and pleasant information. Moreover, valence effects did not yield any clear evidence for hemisphere dominance supporting models claiming that each hemisphere contributes to emotion processing (e.g., Compton et al., 2005).

Appart from individual or gender-related differences that may account for valence effects in emotional processing, the current findings for pleasant words generally pose some further questions concerning the impact of stimulus valence and arousal on the facilitated processing of emotional stimuli. There exists a large literature showing that stimulus arousal is the critical variable in the facilitated processing of emotionally unpleasant and pleasant stimuli. For highly arousing stimuli generally larger responses to unpleasant as well as pleasant stimuli are reported. For instance, previous EEG and imaging studies suggest that visual processing and amygdala activation is positively correlated with the emotional arousal level of a stimulus (e.g., Bradley et al., 2000, 2003; Kensinger et al., 2004; Phan et al., 2004; Sabatinelli et al., 2005; Schupp et al., 2004b). This arousal effect is especially pronounced for stimuli that obtain the highest arousal ratings such as emotional pictures with specific emotional contents of sex and threat. A recent imaging study found, that viewing of highly valent but low arousing pleasant pictures also enhances visual processing and activation of the amygdala (Mourao-Miranda et al., 2003). In the present EEG (ERP) and fMRI studies, only highly arousing emotional adjectives were used and unpleasant and pleasant adjectives were matched for stimulus arousal on the basis of normative arousal ratings described in study 1. In each experiment slightly different sets of highly arousing emotional and low arousing neutral adjectives were used. The sets of emotional adjectives did not exclusively comprise “sex-” or “threat-” words. In the EEG (ERP) studies arousal effects were most pronounced at early time points of word processing. The functional imaging results suggest that processing of pleasant adjectives facilitates word recognition and amygdala activation when pleasant words are highly arousing. However, enhanced processing of pleasant adjectives did not inhibit startle responses. For pleasant stimuli the relationship between stimulus valence and arousal intensity appears more complex. Normative ratings of emotional pictures and emotional adjectives reported in this work show that in contrast to highly unpleasant stimuli highly pleasant stimuli can be experienced as either arousing or calm and low levels of arousal may bias processing in favour of pleasant stimuli. Accordingly, the covariation between arousal and stimulus valence is less pronounced for pleasant stimuli than for unpleasant stimuli. Thus, the arousal dimension may be a poorer predictor for the activation elicited by pleasant stimuli than by unpleasant stimuli. Indeed, in a recent study using emotional pictures it was found that 79% of the variance in arousal ratings can be explained by unpleasant ratings (e.g., Canli,

Desmond, Zhao, & Gabrieli, 2002). For pleasant stimuli similar findings are still lacking. Future studies are needed to specify the precise interaction between emotional arousal and pleasant valence and the facilitatory impact of arousal on the processing of pleasant stimuli. Concerning the processing of pleasant words future EEG and imaging studies are needed that incorporate high and low arousing emotional adjectives. If arousal is the critical variable for enhanced processing of pleasant adjectives and/or unpleasant adjectives one would generally expect stronger visual processing and amygdala activation for highly arousing than low arousing emotional adjectives. Akin to picture stimuli this arousal effect should be most pronounced for emotional adjectives addressing contents of sex and threat. Perhaps, these "sex-" and "threat-" words may then also lead to the expected motivational priming effects in startle paradigms because previous work with picture stimuli shows that erotic and highly aversive threatening stimuli provoke the largest affective defensive modulation patterns conform to theoretical assumptions (e.g., Lang et al., 1997a). Regarding our understanding of the effects of arousal and valence, a fully consistent picture has yet to emerge for the processing of emotional words. Further research will establish whether or when emotional arousal and valence enhance word processing and how arousal and valence effects may be influenced by additional factors such as individual differences in affect or experimental factors.

The early selection effects found in the current studies also deserve closer attention. In the emotion literature there is ongoing discussion about the question when in the temporal processing stream discrimination of emotional from neutral stimuli takes place. For verbal stimuli the question whether early selection of emotional words requires semantic processing is subject to continuous debate. Some behavioural studies show that emotional words - at least threat words - are still processed preferentially and produce larger peripheral arousal responses than neutral words when words are masked or presented subliminally (e.g., Dijksterhuis et al., 2003; Pratto et al., 1991; Silvert et al., 2004; Windmann et al., 2002). Results have often been interpreted as evidence for an unconscious preattentive processing of emotional words that relies primarily on a fast lexical feature processing of emotional words and not necessarily on the processing of emotional meaning. Concerning ERP studies in healthy subjects, some studies do indeed report very early emotional word processing effects in the P1 potential time window occurring in the first 150 ms (e.g., Ortigue et al., 2004; Skrandies, 1998; Skrandies & Chiu, 2003). However, in the majority of studies including the mentioned ERP studies that presented words very briefly and subliminally, early ERP potential findings in healthy subjects converge showing emotional facilitation within the first 150 - 300 ms after word presentation (e.g., Bernat

et al., 2001; Kissler et al., 2006 for review; Schapkin et al., 2000). In this time window semantic processing may be coarse but definitively possible (e.g., Rubin & Turano, 1992; Sereno et al., 1998). The present EEG (ERP) results support this view. In the EEG-tracings the first significant discrimination of emotional from neutral adjectives was indicated by the early posterior negativity potential and the P2 potential. Particularly early posterior negativity potentials arising around 250 ms after word presentation and originating in occipito-temporal extrastriate cortex regions have proven reliable electrophysiological indicators of early semantic processing (e.g., Hinojosa et al., 2004; Martin-Loeches et al., 2001). The view that early selective processing of emotional words requires at least some form of semantic processing is also encouraged by the fMRI findings demonstrating enhanced activation in the extrastriate visual cortex and the amygdala for pleasant adjectives and studies examining intracranial ERP recordings in the amygdala. Prioritized processing elicited in the first 200 ms by emotionally relevant stimuli such as fearful faces has been confined to a largely subcortical thalamo-amygdala processing (e.g., Krolak-Salmon, Henaff, Vighetto, Bertrand, & Mauguiere, 2004). In spite of the fact that highly threatening words were used, results from intracranial ERP recordings, however, indicate that amygdala activation to emotional words requires further processing from higher-order visual processing areas such as the extrastriate visual cortex (e.g., Nacchache et al., 2005). This cortical processing may include early semantic processing of emotional words in the extrastriate visual cortex and may be reflected by affective modulation of the early posterior negativity potential differentiating emotional from neutral word processing at 200 - 300 ms after word presentation.

The challenge for future EEG research using emotional words is to examine under which circumstances emotional modulation as indexed by the early posterior negativity potential may be expected and what the underlying mechanisms that give rise to this amplified cortical processing are. Using similar set-ups as employed in the RSVP-EEG study (study 2) future studies should investigate patients with selective damage to the amygdale or the primary visual cortex. Examining amygdala damaged patients may clarify the general role of the amygdala in early but also in late ERP modulation effects found for emotional adjectives. If early affective modulation was still apparent in blind sight patients with intact amygdale this would indeed speak for a primarily subcortical processing pathway for verbal stimuli that has so far not been supported neither by intracranial ERP recordings nor by neuroimaging findings. In general, even faster presentation rates than the ones employed in the current RSVP-EEG study (study 2) could be used (e.g., Potter et al., 1987). Moreover, words could be presented subliminally or as perceptually degraded word stimuli. This may elucidate whether emotional adjectives still benefit from early semantic processing in the visual cortex and/or otherwise produce even earlier

ERP differentiation effects in the time window of the P1 potential. Moreover, faster word presentations may also clarify the extent to which emotional words capture attention reflexively without being affected by attentional limitations. Regarding the current RSVP-EEG study, the results demonstrated that particularly unpleasant adjectives show a perceptional processing advantage at a faster processing speed (3 Hz). Combining EEG and imaging methods will give precise information about the interplay between the subcortical and cortical brain structures involved in the selective emotional processing effects.

Future attempts may concern several of the suggestions that have been made above and throughout this chapter. Most important, replication of findings will be of highest priority for future research. To this end, the corpus of adjectives collected for the purpose of the current experiments provides a large sample of emotional words including standardized ratings of German subjects (students) that could be used as a measurement standard in future studies investigating healthy subjects from similar populations. Moreover, replication of findings with similar experimental set-ups but different classes of words such as nouns may prove reasonable for scrutinizing the generalizability of the current findings. Similarities and dissimilarities between the processing of emotional adjectives and other emotional words (e.g. nouns, verbs) or between verbal and non-verbal emotional material, could in future be explained on a common theoretical background. The bio-informational theory of emotion provides a useful theoretical approach to this end.

VII. Zusammenfassung

Zahlreiche Forschungsergebnisse auf dem Gebiet der affektiven Neurowissenschaften zeigen, wie emotionale Reize selektiv unsere Wahrnehmung, unser Denken und unser Verhalten lenken. Während eine Vielzahl neurophysiologischer Arbeiten zur Verarbeitung konkret-anschaulicher emotionaler Reize existiert, ist bisher relativ wenig über die zerebrale Verarbeitung und funktionale Repräsentation emotional sprachlicher Reize bei gesunden Personen bekannt. Ziel der vorliegenden Dissertation war es, die selektive Verarbeitung emotionaler Wörter bei gesunden, jungen Erwachsenen in ausgewählten Paradigmen der Emotionsforschung systematisch zu untersuchen. Durch die Verwendung ereigniskorrelierter Potentiale (EKPs) aus dem EEG und bildgebender Verfahren wie der funktionellen Magnetresonanztomographie (fMRI) war es möglich, detaillierte Aussagen zum zeitlichen Verlauf sowie der an der selektiven Verarbeitung emotionaler Wörter beteiligten Hirnstrukturen zu treffen. Zusätzlich wurden die Auswirkungen der Verarbeitung emotionaler Bedeutung von Wörtern auf Reaktionsdispositionen und das Langzeit-Gedächtnis durch den Einsatz peripherphysiologischer Maße des Schreckreflexes und behavioraler Gedächtnistests überprüft. Diese multidimensionale Analyse machte es möglich, die Ergebnisse im Rahmen der bioinformationalen Emotionstheorie von Peter Lang (1979) genauer zu beschreiben und mit bisherigen Ergebnissen für konkret-anschauliche Reize zu vergleichen.

Zusammengenommen erlauben die einzelnen Studienergebnisse einen interessanten Einblick in die subjektive Bewertung emotionaler Wörter sowie die zerebrale Verarbeitung emotional sprachlicher visueller Reize und deren Auswirkung auf Langzeit-Gedächtnisfunktionen und einfache Verhaltensmuster bei gesunden Personen.

In Studie 1 konnte bestätigt werden, dass emotional bedeutsame Wörter anhand primärer Emotionsdimensionen der emotionalen Valenz (angenehm - unangenehm) und des emotionalen Arousal (beruhigend - erregend) beurteilt werden. Die Analyse affektiver Urteile von 45 studentischen Versuchspersonen ergab die für emotionales Material typische U-förmige Urteilsverteilung im zweidimensionalen affektiven Raum, wie sie auch in studentischen Normstichproben für das internationale Bild- (IAPS) und Ton- (IADS) Material sowie in für den englischsprachigen Raum erhobenen Wortkatalogen berichtet wird (z.B. Bradley et al., 1999a, b; Lang et al., 1997b, 2005). Die EEG-Befunde (Studie 2, Studie 4) wie auch die fMRI-Befunde (Studie 3) zeigen, dass die emotionale Bedeutung von Wörtern verstärkt verarbeitet und einer intensiveren Stimulusevaluation unterzogen wird. Dabei lassen vor allem die EEG-Studien erkennen, dass emotionale Bewertungsprozesse von sprachlichem Material im Gehirn, spontan

schnellen Veränderungen unterliegen. Eine verstärkte Verarbeitung hoch erregender, unangenehmer, aber auch angenehmer Wörter in den ersten 200 - 300 ms belegt, dass emotional verbale Reize ebenso wie non-verbale emotionale Reize (z.B. emotionale Bilder) schnell detektiert, identifiziert und bezüglich ihrer motivationalen Relevanz kategorisiert werden. Konsistent mit der Annahme, dass emotionale Reize spontan Aufmerksamkeit auf sich ziehen, zeigte sich ein früher Selektionsvorteil emotional angenehmer und insbesondere unangenehmer Wörter sogar bei stärkerer Limitierung von visuellen Aufmerksamkeitsressourcen (Studie 2). Über die einzelnen EEG-Experimente wurde deutlich, dass vor allem angenehme Adjektive bei längerer Wortdarbietung (z.B. 1000 ms – 5000 ms) auch zu späteren Zeitpunkten der Reizanalyse weiterhin intensiver enkodiert und evaluiert werden und entsprechend besser erinnert werden. Die fMRI-Befunde belegen, dass diese zeitlich andauernde erhöhte Verarbeitung emotional angenehmer Adjektive mit einer u.a. stärkeren Aktivierung in visuo-limbischen Netzwerken und in Hirnstrukturen mit semantischen-, attentiven-, motorischen- und Gedächtnisfunktionen assoziiert ist. Eine intensive Enkodierung angenehmer Wörter wird - wie die Ergebnisse der EEG-EMG Studie (Studie 4) - erkennen lassen, jedoch unterbrochen, sobald ein hoch aversiver Stimulus wie ein Schreckton, eine rasche Reorientierung auf potenziell gefährliche Umweltreize verlangt.

Die Verwendung vor allem passiver Reizexpositionsparadigmen lässt den Schluss zu, dass es sich bei den vorliegenden Befunden um einen natürlichen Selektionsbias emotional unangenehmer und angenehmer Reize bei gesunden Personen handelt, wonach emotionale Wortbedeutungen, in Abhängigkeit ihres emotionalen Arousals und ihrer motivationalen Signifikanz, unterschiedlich stark verarbeitet werden. Während zu frühen Zeitpunkten der Reizanalyse eine stärkere Verarbeitung unangenehmer und emotional interessanter Wortinhalte Befunde einer raschen Diskrimination potenziell gefährlicher und emotional bedeutsamer Reize bekräftigt, unterstützt eine tendenziell intensivere Verarbeitung emotional erregender, angenehmer Adjektive Befunde einer stärkeren Präferenz der Enkodierung stimmungskongruenter angenehmer Information bei gesunden Personen (z.B. Ferré, 2003; Kiefer et al., in press), betont den Einfluss positiver Emotionen in der Informationsverarbeitung (z.B. Diener et al., 1996; Fredrickson et al, 2005; Isen, 2001) und bekräftigt eine Beteiligung des defensiven und des appetitiven motivationalen Systems bei der Verarbeitung sprachlicher emotionaler Reize.

VIII. Summary

Basic research in the field of affective neuroscience shows how emotional stimuli influence our perception, thoughts and behaviour. However, in relation to neurophysiologic studies investigating the processing of emotionally concrete stimuli such as emotional pictures or faces comparatively little is known about the cerebral processes associated with the processing of emotionally verbal material. The current doctoral thesis aimed to provide systematic research concerning the selective processing of emotional words in healthy subjects. Precise information about the time course of emotional word processing as well as its functional representation in the brain was assessed by means of event-related electrocortical potentials (ERP-EEG) and functional magnetic resonance imaging (fMRI) methods. Additional research questions concerned the influence of emotional meaning processing on the modulation of emotional responses such as the defensive startle reflex and on long-term memory. This multidimensional approach allowed the comparison of emotional responses elicited by emotional words with those reported for emotionally concrete picture stimuli and the interpretation of the current findings in terms of assumptions derived from the bio-informational theory of emotion, proposed by Peter Lang and collaborators (Lang, 1979).

The present studies provide important insights in how emotional meaning is evaluated and processed in the brain. Study 1 demonstrated that emotionally relevant words are evaluated according to the two major evaluative dimensions of emotional valence and emotional arousal. Emotional valence and arousal ratings of adjectives assessed in a normative sample of student subjects showed the typical u-shaped distribution of affective material in affective space. Similar distributions have been reported for normative student ratings of emotional pictures, affective sounds and English words (e.g., Bradley et al., 1999a, b; Lang et al., 1997b, 2005). The EEG (ERP) studies (study 2 and study 4) as well as the imaging study (study 3) consistently found, that words are selected according to their emotional significance. The EEG studies demonstrated that the time course of emotional word processing is variable and changes within milliseconds. Akin to emotional picture stimuli, unpleasant as well as pleasant words were rapidly identified and discriminated from neutral words within the first 200 – 300 milliseconds. In line with the view that emotional stimuli capture attention rapidly emotional and specifically unpleasant words were processed in a facilitated manner at a perceptual processing stage even when processing load was high and attentional resources were limited. Concerning later processing stages and longer word durations, only pleasant words were selected for a more detailed stimulus evaluation and consolidation process in memory. The fMRI experiment (study 3) showed that

this temporally prolonged processing of pleasant in contrast to unpleasant and neutral adjectives was associated with a pronounced activation pattern in cortico-limbic brain networks with visual, mnestic and emotional functions as well as in frontal brain regions associated with motor control and parietal and temporal brain regions involved in attention and the processing of meaning. However, the combined EEG (ERP)-EMG study (study 4) revealed, that a more detailed encoding of pleasant words was interrupted as soon as survival protecting startle eliciting tones require rapid reorientation to the environment to deal adaptively with potential danger.

In a natural viewing context, such as during passive viewing and covert evaluation tasks these spontaneously occurring unpleasant-pleasant processing asymmetries clearly reflect a natural bias in emotional processing in healthy subjects: While at early levels of stimulus processing the findings attest that unpleasant valence and emotional arousal modulate the emotional selection process to guarantee rapid discrimination of potentially dangerous and emotionally interesting stimuli from neutral ones, a stronger tendency to concern oneself with pleasant than unpleasant events appears to guide selective processing at successive stages of word perception bolstering semantic integration of pleasant information and its consolidation in memory. This preference for pleasant words agrees with findings showing facilitated encoding of mood-congruent pleasant information in healthy subjects (e.g., Ferré, 2003; Kiefer et al., in press), underscores the role of pleasant emotions in information processing (e.g., Diener et al., 1996; Fredrickson et al, 2005; Isen, 2001) and confirms a contribution of the defensive as well as the appetitive motive system in the selective processing of verbal emotional material.

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Appendix

Participants` instruction used for the acquisition of emotional valence and arousal ratings of adjectives on the Self-Assessment Manikin Scales of emotional valence and arousal.

Liebe Versuchsteilnehmerin, lieber Versuchsteilnehmer,

herzlichen Dank für Ihr Interesse an unserem Experiment!

Im Rahmen eines unserer Projekte am Lehrstuhl für Klinische Psychologie an der Universität Konstanz untersuchen wir, wie Wörter emotional beurteilt werden. Dazu benötigen wir dringend Personen, welche die von uns ausgewählten Wörter auf zwei Dimensionen - der emotionalen Valenz und der emotionalen Erregung/Arousal - bewerten. Dies ist notwendig, um standardisierte Wortlisten zu erzeugen. Durch Ihre Teilnahme an diesem Experiment leisten Sie hierzu einen wesentlichen Beitrag!

Alle Versuchsteilnehmerinnen und Versuchsteilnehmer erhalten bei Abgabe eines vollständig ausgefüllten Fragebogens eine Aufwandsentschädigung von 4€. Für Studierende des Fachs Psychologie besteht die Möglichkeit einer Anrechnung als Versuchspersonenstunde.

Bitte tragen Sie auf den dafür vorgesehenen Platzhaltern Ihr Studienfach, Ihre Nationalität, Ihr Alter und Ihr Geschlecht ein. Dies ist notwendig, um Geschlechts-, Alterseffekte sowie kulturelle Unterschiede kontrollieren zu können. Ihre Angaben werden im Sinne des Datenschutzes behandelt.

Persönliche Daten:

Nationalität: _____ VP-Nummer: _____

Muttersprache: _____

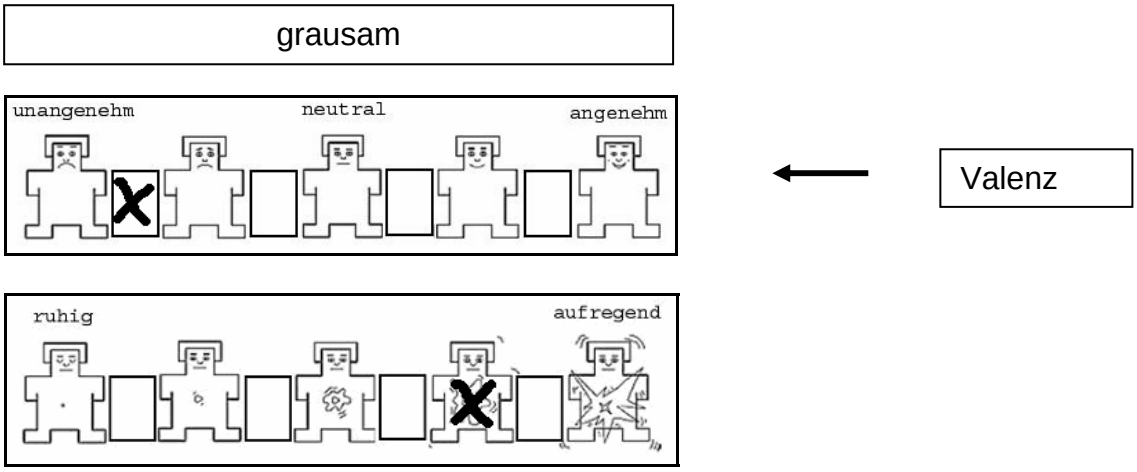
Studienfach: _____

Semester: _____

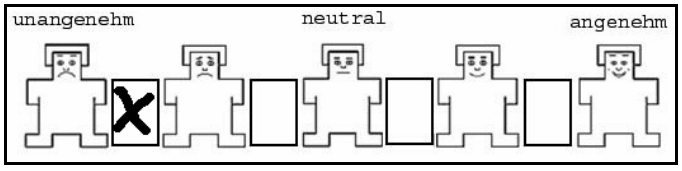
Geschlecht: _____

Auf den folgenden Seiten finden Sie verschiedene Adjektive. Zu jedem Adjektiv gehören je 2 Beurteilungsskalen, die unterhalb des Adjektivs angeordnet sind.

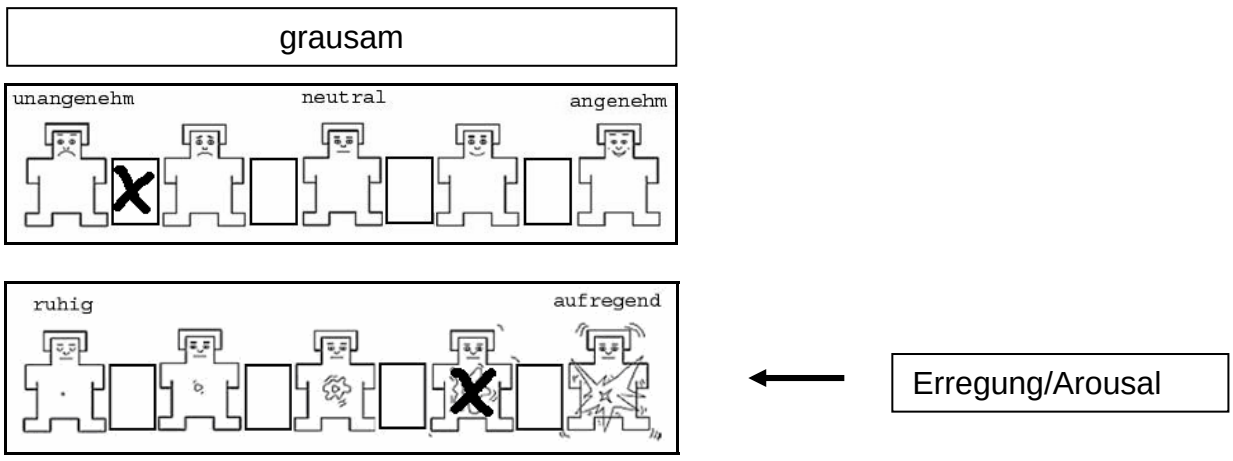
Beispiel: Valenz



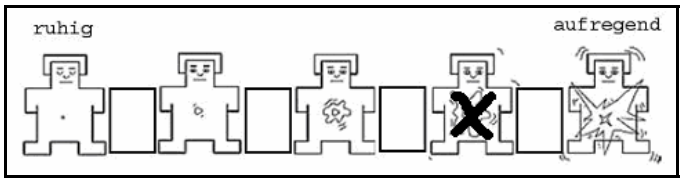
Die erste der beiden Skalen (Valenz) zeigt 5 Männchen, deren Gesichtsausdruck von unangenehm (links außen) bis angenehm (rechts außen) variiert. Auf dieser Skala sollen Sie angeben, welchen emotionalen Gefühlszustand (Valenz) das Adjektiv bei Ihnen erzeugt. Wichtig ist, dass Sie **nicht das Wort an sich beurteilen, sondern die emotionale Reaktion, die das Wort bei Ihnen spontan hervorruft, ohne dass sie lange darüber nachdenken.** Je nachdem, welche emotionale Reaktion das Wort bei Ihnen spontan hervorruft, kennzeichnen Sie dies bitte auf dem entsprechenden Männchen oder einem Platzhalter dazwischen mit einem Kreuz. Sie haben also neun Ankreuzmöglichkeiten. Wenn das Wort *„grausam"* bei Ihnen eine deutlich unangenehme emotionale Reaktion hervorruft, würden Sie die Skala beispielsweise folgendermaßen ausfüllen:



Beispiel: Erregung/Arousal



Auf der zweiten Skala („Erregung/Arousal“) sollen Sie angeben, wie stark Sie dieses Wort erregt/aktiviert oder beruhigt/entspannt. Auch hier gilt, **Sie sollen nicht das Wort an sich beurteilen, sondern die Erregung oder Beruhigung, die das Wort bei Ihnen spontan hervorruft.** Die Skala („Erregung/Arousal“) zeigt ebenfalls 5 Männchen. Das rechte äußere Männchen hat einen “explodierenden Magen“, was für sehr starke Erregung steht. Das linke Männchen hat einen Punkt als Magen, was sehr starke Beruhigung darstellen soll. Wie oben haben Sie neun Ankreuzmöglichkeiten. Wenn das Wort *„hübsch“* oder *„grausam“* Sie emotional erregt, würden Sie die zweite Skala beispielsweise folgendermaßen ausfüllen:



Es gibt keine falschen oder richtigen Antworten. Wichtig ist, dass Sie ehrlich und spontan Ihren Gefühlszustand angeben, unabhängig davon, ob Sie glauben, dass er sozial erwünscht oder unerwünscht sein könnte!

Kennzeichnen Sie Ihre Antwort bitte durch ein Kreuz. Geben Sie pro Wort bitte auf beiden Skalen eine Antwort, auch wenn Sie sich unsicher sind!

Vielen Dank für Ihre Mithilfe!

Corpus of 486 emotional and neutral German adjectives

Adjectives are presented in alphabetical order in the first column. Mean SAM valence and arousal ratings of 45 student subjects (26 females and 19 males; mean age: 25.7 years) of the University of Konstanz are presented for each adjective in the second and fourth columns. Mean standard deviations (SDV) of valence and arousal ratings are displayed in columns 3 and 5. The range and direction of the SAM ratings are as follows: Valence = 9 (extremely pleasant) to 1 (extremely unpleasant), arousal = 9 (extremely arousing) to 1 (not at all arousing).

Word	Mean Valence	SDV Valence	Mean Arousal	SDV Arousal
abergläubisch	3.85	1.21	3.97	1.85
abgebrüht	4.03	1.64	4.85	2.16
abgehackt	3.06	1.33	5.31	1.95
abgestochen	2.17	1.38	6.83	1.76
abhängig	2.91	1.25	4.66	1.78
abstoßend	2.26	0.89	6.11	1.68
abwesend	4.31	1.16	3.77	1.97
adrett	6.11	1.13	4.17	1.81
äffisch	4.03	1.24	5.41	1.78
ahnungslos	3.83	0.89	4.86	2.09
anatomisch	5.23	0.88	3.54	1.62
angepasst	4.60	1.40	2.94	1.80
ängstlich	3.17	0.92	5.49	1.76
anhänglich	5.49	1.67	3.74	1.67
animalisch	4.46	1.20	5.91	1.65
anlehnungsbedürftig	5.54	1.58	3.37	1.82
anstrengend	4.06	1.73	5.71	1.81
anwesend	5.26	1.04	2.83	1.90
anziehend	7.11	1.13	5.89	2.30
argwöhnisch	3.46	0.95	4.89	1.73
arrogant	2.11	0.96	6.43	1.77
asozial	2.31	0.99	5.83	2.06
ätzend	2.71	1.13	5.80	1.59
aufbrausend	3.46	1.48	6.85	1.56
auffallend	5.51	1.25	4.69	2.00
aufgedunsen	2.74	1.07	4.51	2.03
aufregend	6.46	1.42	6.46	1.85
aufrichtig	6.97	0.98	3.26	1.31
ausdauernd	6.69	1.35	3.31	1.60
ausgeglichen	7.43	1.46	2.09	1.25
ausgeheilt	6.66	1.21	2.74	1.20
ausgelassen	6.46	1.22	5.44	1.86
ausgeraubt	2.34	0.97	6.74	1.79
barmherzig	6.69	1.18	3.09	1.58
bedachtsam	5.80	1.18	2.89	1.28
bedenkenlos	5.40	1.75	3.49	1.76
bedrohlich	2.57	0.88	6.43	1.52
beeinflussend	3.53	1.05	5.21	1.75
begraben	2.97	1.32	4.63	2.25
beherzt	7.03	1.20	4.80	2.00
behutsam	6.77	1.03	2.34	1.00

bekannt	6.06	1.11	3.03	1.85
belanglos	4.43	0.98	3.34	1.88
belebt	6.51	1.09	5.40	1.90
beleidigt	2.80	1.30	5.80	1.39
belesen	6.74	1.27	2.63	1.86
belogen	2.34	1.08	6.89	1.94
berechenbar	4.51	1.40	4.00	1.81
beschäftigt	5.54	1.24	3.89	2.10
beschnitten	3.26	1.36	5.29	2.47
beschuldigt	2.54	1.04	6.49	1.85
besonnen	6.54	1.48	2.20	1.16
besorgt	3.26	1.36	5.20	1.75
bestialisch	1.91	1.01	7.20	1.47
bestimmt	5.34	0.94	4.31	2.07
beunruhigend	3.46	1.54	5.83	1.93
beweglich	6.37	1.24	3.91	1.72
bewusstlos	2.80	1.21	5.09	2.38
bieder	3.31	1.21	3.56	1.99
bildhübsch	7.46	1.46	4.83	2.26
billig	4.97	1.52	3.14	1.65
bizarr	4.57	1.54	4.66	2.14
blamiert	2.20	1.55	7.24	1.56
blond	6.17	1.74	4.51	2.19
blutig	2.40	1.29	6.26	1.75
böse	2.49	1.31	6.00	2.01
brav	5.23	1.50	2.85	1.76
breit	4.94	0.73	3.26	2.19
brüderlich	6.89	0.93	3.26	1.67
brutal	1.69	0.80	7.34	1.75
bürgerlich	4.80	1.11	3.71	1.64
dämlich	2.71	1.15	5.11	1.79
diskret	6.29	1.34	3.17	1.48
diszipliniert	5.91	1.22	3.74	1.46
doof	3.00	1.24	4.24	2.00
dreist	3.60	1.52	5.94	1.75
dunkel	4.34	1.33	4.60	2.25
durchgebrannt	4.26	1.54	5.91	2.36
durchgedreht	3.54	1.60	6.14	1.91
durchtrieben	3.66	1.59	6.23	1.33
dürr	3.69	1.39	4.69	1.73
dynamisch	6.69	1.21	5.20	2.03
eckig	4.71	0.71	3.47	1.85
ehrenhaft	6.37	1.37	3.37	1.80
eigenwillig	4.74	1.74	4.83	1.90
einfallslos	3.03	1.04	4.63	2.65
eingebildet	2.77	1.14	5.63	1.99
einsam	2.49	1.09	3.74	1.70
einsilbig	3.94	1.17	3.67	1.80
eiskalt	3.31	1.60	4.97	1.85
eitel	3.57	1.09	4.43	1.75
eitrig	2.17	0.95	6.37	1.50
ekelhaft	2.06	0.76	6.44	1.78
enthaltsam	4.29	1.49	3.38	1.58
enthusiastisch	6.69	1.43	5.74	1.93
entlarvt	3.91	1.74	5.69	2.05
entmutigt	3.11	1.16	3.89	1.69
entstellt	2.34	1.06	6.31	1.73

entzückend	7.00	1.43	4.37	2.03
erbarmungslos	2.29	1.10	6.11	1.91
erbrochen	2.31	1.21	6.17	1.82
erfolgreich	7.09	1.40	4.74	2.05
erfroren	2.63	1.61	5.17	2.19
erholsam	7.09	0.98	2.34	1.26
ermüdend	3.06	0.97	3.51	1.87
ernsthaft	5.31	0.90	3.29	1.56
erotisch	7.46	1.20	6.77	1.73
erregbar	4.91	1.58	5.91	1.90
erregt	6.34	1.64	7.15	1.64
erstarrt	3.49	0.95	4.57	2.03
etabliert	5.63	1.14	2.57	1.42
euphorisch	6.83	1.65	6.31	2.03
explodiert	3.43	1.69	6.60	1.88
fair	7.37	1.44	3.17	1.56
fanatisch	2.71	1.51	6.86	1.57
feurig	6.51	1.34	6.89	1.59
findig	6.15	1.05	4.03	1.78
flüssig	5.69	1.05	3.23	1.96
förmlich	4.60	1.22	3.20	1.69
fremd	4.20	1.02	4.83	1.60
freundlich	7.60	1.14	3.29	1.84
friedlich	7.00	1.75	2.44	1.64
frigide	2.97	1.40	4.00	2.01
frivol	4.97	1.68	4.76	2.15
fromm	4.97	1.56	2.94	1.91
furchtbar	2.51	1.07	6.20	2.03
fürsorglich	6.91	1.24	3.26	1.58
geduldig	6.66	1.26	2.29	1.10
gefällig	5.40	1.72	3.80	1.61
gefesselt	3.74	2.02	5.91	2.15
gefeuert	2.63	1.61	6.29	1.81
gefoltert	1.66	1.24	7.53	1.67
gefühlvoll	7.57	1.14	4.46	2.33
gehemmt	3.23	0.84	3.97	1.84
geistesgegenwärtig	6.94	0.91	4.40	2.16
geistlos	3.40	0.98	3.46	1.88
gekünstelt	3.17	0.79	4.31	1.79
gelassen	7.03	1.12	2.40	1.33
gelöst	6.60	1.14	2.86	1.57
gelyncht	1.85	1.13	7.12	1.92
genau	5.74	1.04	2.89	1.69
gepflogen	4.91	0.83	3.82	1.49
gerecht	7.17	1.20	3.20	1.45
geschickt	6.77	0.94	3.80	1.64
geschlagen	2.47	1.21	6.35	1.69
gespannt	5.66	1.30	5.66	2.34
gesprächig	5.86	1.42	4.83	1.46
getreten	2.31	0.90	6.46	1.85
gewöhnlich	4.37	0.77	3.17	1.85
gierig	3.06	1.21	5.71	1.86
giftig	2.46	1.31	6.34	1.61
gigantisch	6.80	1.26	5.60	1.79
gleichgültig	3.60	1.40	3.94	2.17
glücklich	8.06	1.24	4.66	2.26
gönnerhaft	5.40	1.63	3.94	1.64

göttlich	6.97	1.52	4.54	2.11
grauenvoll	2.00	1.21	6.80	1.51
grausam	1.89	1.21	7.38	1.54
groß	5.71	1.25	3.23	1.94
großartig	7.40	1.09	5.60	2.02
großspurig	3.71	1.18	4.89	2.11
großzügig	6.83	1.34	3.89	1.68
gruselig	3.60	1.61	6.49	1.76
haarig	3.20	1.53	5.14	1.94
habgierig	2.14	0.81	5.80	1.94
hämisch	2.97	1.18	5.69	1.71
harmlos	5.74	1.38	2.26	1.54
hartnäckig	4.74	1.44	4.89	1.83
hässlich	2.63	0.97	4.71	1.98
häuslich	5.29	1.51	2.23	1.40
heiter	7.53	1.02	4.15	1.92
hell	6.89	1.30	3.20	1.66
hemmungslos	4.71	1.84	6.46	1.54
herablassend	2.29	0.96	5.83	2.16
heroisch	5.31	2.03	5.43	2.10
herzlich	7.63	1.29	3.91	2.04
heuchlerisch	2.57	1.40	6.23	1.88
hilflos	2.83	0.86	5.66	1.51
hilfsbereit	7.50	0.99	3.59	1.92
hinfällig	3.77	1.11	4.34	1.94
hingebungsvoll	6.71	1.30	4.80	1.92
hinterhältig	2.43	1.01	6.57	1.82
hirnlos	2.97	1.32	4.80	2.27
hoch	5.57	0.92	4.26	2.18
höflich	6.49	1.44	3.06	1.39
hübsch	7.46	1.12	4.14	1.83
humorvoll	7.74	1.34	4.47	2.16
ideal	6.82	1.31	3.62	1.74
impotent	2.40	1.19	5.49	2.17
impulsiv	5.49	1.48	6.63	1.61
infiziert	2.14	1.17	6.66	1.94
innerlich	5.69	1.11	3.57	2.05
interessant	7.17	1.18	5.43	1.94
jähzornig	2.17	0.86	6.91	1.58
jugendlich	6.77	1.35	4.06	2.04
kaltblütig	2.29	1.18	6.40	2.20
kameradschaftlich	7.20	1.23	3.77	1.90
karg	3.76	1.05	3.03	1.55
katastrophal	2.46	1.22	6.83	1.44
klamm	3.37	1.17	4.06	1.73
klassisch	5.54	1.24	3.20	1.62
klein	5.23	1.26	2.77	1.78
kleinkariert	2.94	1.11	5.43	1.93
kleinlaut	3.60	0.88	3.66	1.70
kleinlich	3.31	1.23	4.97	1.87
kokett	5.74	1.38	4.88	1.47
komisch	6.14	1.80	5.37	1.90
kompliziert	4.26	1.12	4.65	1.94
kompromissbereit	6.94	1.08	3.26	1.38
konventionell	4.26	1.09	3.71	1.82
konzentriert	6.57	1.09	3.60	1.74
korrupt	2.43	1.17	6.26	1.87

kräftig	6.74	1.15	4.37	1.61
krankhaft	2.74	0.70	5.23	2.04
kriminell	2.59	1.26	5.97	2.14
künstlich	3.86	1.09	3.69	2.01
kuschelig	7.94	1.14	3.66	2.24
labil	3.51	1.34	4.11	1.92
lächerlich	3.60	1.48	5.54	1.85
laienhaft	3.80	1.21	4.06	1.71
lammfromm	5.37	1.37	2.40	1.33
launisch	3.09	0.82	5.46	1.82
lausig	3.14	1.03	4.49	1.84
lautlos	4.97	0.62	2.77	1.83
lebenslustig	7.89	0.93	5.26	2.09
leblos	2.57	1.33	4.11	2.07
lecker	7.37	0.97	4.11	2.15
leer	4.03	1.27	2.80	1.66
leichtfertig	4.00	1.46	5.43	1.82
leidend	2.54	1.34	5.54	1.88
leidenschaftlich	7.23	1.70	7.26	1.58
leise	5.63	1.26	2.26	1.29
leistungsfähig	6.74	1.19	4.68	1.92
lesbisch	4.20	1.41	4.94	2.18
lieblich	6.91	1.48	3.80	1.80
listig	4.66	2.09	5.06	1.95
löblich	6.06	1.21	2.97	1.64
lügnerisch	2.40	0.74	5.62	1.94
lüstern	4.20	2.00	6.31	1.53
lustig	7.37	1.24	5.11	1.59
manierlich	5.65	1.43	3.00	1.44
männlich	6.46	1.54	4.71	2.27
massakriert	1.63	0.88	7.46	1.74
maßlos	3.29	1.30	4.91	2.25
matt	3.86	1.24	2.74	1.56
missbraucht	1.40	0.55	7.46	1.63
misshandelt	1.63	1.40	7.71	1.69
mittelmäßig	3.94	1.37	3.57	1.82
modern	5.86	1.26	3.77	1.97
mulmig	3.23	0.94	5.63	1.61
munter	7.20	0.96	4.86	1.80
mürrisch	2.74	1.01	4.77	1.91
nackt	5.86	1.52	5.60	2.13
naiv	4.09	1.29	3.63	1.96
natürlich	6.74	1.29	3.11	1.76
neidisch	2.37	1.06	6.49	1.63
nervig	2.74	0.85	6.03	1.81
nervös	3.26	1.52	7.03	1.40
nett	6.77	1.21	2.83	1.56
neuartig	5.79	1.20	4.47	1.96
neurotisch	3.14	1.19	5.26	1.95
neutral	5.09	0.95	3.26	1.79
nichtssagend	4.00	1.21	2.91	1.62
niedergeschossen	1.91	1.20	6.43	2.06
niedlich	6.57	1.50	3.51	1.65
nobel	6.11	1.47	3.34	1.55
normal	4.71	0.79	3.51	1.85
objektiv	5.86	1.17	2.86	1.54
öde	2.97	1.01	3.54	2.21

ohnmächtig	2.71	1.20	5.43	1.80
operiert	3.66	1.19	5.23	1.77
optimistisch	7.17	1.29	4.32	1.93
ordinär	2.91	0.98	5.09	2.16
panisch	2.40	1.22	7.23	1.37
perfekt	6.71	1.71	4.49	2.27
persönlich	5.86	0.97	3.29	1.76
pervers	2.47	1.21	6.76	1.78
pfiffig	6.77	0.97	5.26	1.58
phantasievoll	7.29	1.07	5.00	1.91
phantastisch	7.34	1.59	5.51	1.92
platonisch	5.26	1.31	3.26	1.75
plump	3.29	0.99	4.23	2.03
potent	6.71	1.27	5.20	1.98
präzise	6.06	1.41	3.03	1.76
privat	5.80	1.13	3.31	1.76
produktiv	6.53	1.16	4.24	1.83
progressiv	5.54	1.63	4.49	1.82
raffiniert	6.09	1.31	5.12	1.87
rasend	3.94	1.53	6.20	2.44
rastlos	3.86	1.14	5.91	2.05
rausgeschmissen	2.69	0.93	6.26	1.52
real	5.46	1.12	3.09	1.52
rechthaberisch	2.29	0.83	5.88	1.90
redegewandt	6.86	1.17	3.97	2.18
redselig	5.06	1.35	4.77	1.88
reif	6.37	1.48	3.54	1.63
reinlich	6.03	1.52	3.63	1.72
reizend	6.80	1.11	4.49	1.93
revolutionär	5.91	1.36	6.46	1.69
rigoros	4.23	1.26	5.37	1.61
ruchlos	3.88	1.17	4.97	1.93
rücksichtslos	2.14	0.81	6.20	1.81
ruhelos	3.60	1.38	5.46	2.21
rühmlich	5.91	1.42	3.83	1.82
salopp	5.17	1.15	4.31	1.51
salzig	5.00	1.03	3.60	1.99
sanft	7.17	0.98	2.40	1.59
sanftmütig	6.94	1.21	2.49	1.09
schäbig	2.77	1.03	4.85	1.79
schamlos	3.40	1.33	5.09	1.92
scharf	5.37	1.75	5.60	1.75
scharfsinnig	6.69	1.08	4.63	1.90
schaurig	3.66	1.49	6.29	1.86
scheinheilig	3.03	1.20	5.09	2.01
scheu	4.14	1.17	4.26	1.84
scheußlich	2.50	1.05	6.12	1.67
schizophren	2.89	1.08	5.40	2.00
schlampig	3.09	1.42	5.86	1.93
schlau	6.94	0.98	4.29	1.55
schleierhaft	4.11	1.13	3.54	1.93
schlicht	5.43	1.38	2.69	1.35
schlitzohrig	5.00	1.51	5.18	1.70
schlüpfrig	4.51	1.48	5.26	1.81
schmachvoll	3.31	1.11	4.49	2.06
schmerzend	2.54	1.36	6.43	1.60
schmierig	2.60	1.03	5.11	2.14

schnell	5.89	1.08	4.94	2.21
schön	7.54	1.17	3.20	1.84
schreckhaft	3.57	1.01	6.37	1.44
schrecklich	2.60	0.95	6.17	1.56
schwach	3.40	0.98	3.97	1.99
schwächlich	3.31	0.99	4.03	1.62
schwachsinnig	2.94	1.28	4.83	2.01
schwärmerisch	6.34	1.68	5.51	1.63
schweigsam	4.80	1.61	3.23	2.03
schwerelos	6.77	1.35	3.54	2.11
schwermütig	2.97	0.92	3.91	1.82
schwul	4.14	1.42	4.17	2.20
schwungvoll	6.94	0.87	5.46	2.05
seelenverwandt	7.37	1.19	4.11	1.97
selbstgefällig	3.00	0.94	4.69	2.08
selbstherrlich	2.74	1.04	5.54	1.72
selbstlos	5.46	1.74	3.85	1.64
selbstsicher	7.00	1.55	3.66	1.68
sentimental	4.77	1.44	3.83	1.71
sexistisch	2.63	1.21	5.97	2.11
sexuell	6.11	1.45	5.97	1.95
sicher	7.20	1.16	2.69	1.32
sinngemäß	5.51	1.07	2.86	1.77
sinnlich	7.09	1.09	4.94	2.09
sitzengelassen	2.14	1.12	6.66	1.78
skelettiert	2.43	1.22	5.83	2.23
skurril	5.23	1.40	5.34	1.70
smart	6.20	1.53	4.06	2.01
solide	5.54	1.54	2.66	1.57
sorgenvoll	2.89	1.05	5.54	1.75
spannend	6.77	1.00	7.03	1.62
spaßig	7.09	1.07	5.17	1.46
speiübel	1.63	0.91	6.34	1.81
spitzfindig	4.77	1.80	4.71	1.74
sportlich	6.71	1.32	4.17	2.32
stämmig	4.49	1.01	3.37	2.10
standhaft	6.34	1.08	3.37	1.44
starrsinnig	3.03	1.12	5.89	1.59
stickig	2.74	0.98	4.91	2.01
streberhaft	3.97	1.67	4.71	1.92
strebsam	5.91	1.50	4.17	1.93
streng	3.43	1.04	5.17	1.71
struppig	5.23	1.29	3.97	1.74
stumpfsinnig	2.89	0.90	4.80	2.04
stupide	3.00	0.69	4.09	2.01
stur	2.86	1.00	6.09	1.83
subjektiv	4.97	1.27	3.76	1.72
sündig	3.86	1.59	5.00	2.07
super	7.66	1.11	5.23	2.37
sympathisch	7.77	0.91	3.86	1.85
tapfer	6.77	1.33	4.66	1.89
taub	2.68	1.25	4.09	1.93
teuflisch	2.77	1.42	6.00	2.16
tierisch	5.00	1.50	4.91	2.22
tolerant	7.29	1.30	3.26	1.66
toll	7.23	1.06	4.69	2.13
tölpelhaft	3.91	1.60	5.49	1.63

träge	3.14	1.17	2.80	1.71
traurig	2.77	1.17	3.91	1.85
treu	7.49	1.22	3.51	2.23
triumphierend	5.89	1.45	5.74	1.48
trostlos	2.31	0.90	4.60	1.75
tüchtig	6.43	1.29	3.91	1.65
typisch	4.66	1.06	3.76	1.94
tyrannisch	1.94	0.80	6.94	1.41
überlegt	6.38	1.13	3.18	1.42
überschwänglich	6.06	1.43	5.69	2.05
überzeugend	6.49	0.78	3.49	1.56
umgelegt	3.29	1.47	5.29	2.04
umsonst	5.51	2.02	4.31	2.08
umständlich	3.46	0.98	5.40	1.80
unangenehm	2.49	1.01	5.26	1.52
unanständig	4.03	1.40	4.97	1.82
unausweichlich	3.60	0.81	4.71	2.07
unbekannt	4.74	1.24	4.80	2.10
unbekümmert	6.94	1.43	3.46	1.58
unbequem	3.31	1.23	5.00	1.77
unbewusst	4.54	1.07	3.71	2.01
unerfahren	4.57	1.01	3.69	1.95
ungebildet	3.40	1.29	3.69	2.03
ungezwungen	6.66	1.14	3.66	1.51
unheilbar	1.83	0.98	6.60	1.96
unkonventionell	5.80	1.35	4.74	1.85
unruhig	3.17	1.10	6.43	1.42
unsterblich	5.94	1.73	4.31	1.86
unterhaltend	6.57	1.12	4.66	2.00
unterwürfig	2.60	1.17	4.69	1.79
untreu	2.09	1.01	7.20	1.94
unverschämt	4.06	1.88	5.71	2.11
unverschuldet	5.03	1.52	4.26	2.16
unzertrennlich	6.06	1.14	4.17	1.85
verdächtig	3.69	1.13	5.46	1.72
verdammt	2.79	1.07	5.65	1.94
verdurstet	2.06	1.18	6.06	2.15
verendet	2.51	1.22	5.03	1.93
verfault	2.26	1.12	5.37	2.35
verflucht	2.83	1.10	5.94	2.00
verführerisch	7.20	1.43	6.66	1.57
vergewaltigt	1.37	0.73	8.00	1.51
vergnügt	7.69	1.02	4.77	1.97
verhasst	2.09	0.98	7.14	1.46
verklärt	4.51	1.09	4.06	1.67
verkorkst	3.17	1.18	4.85	1.94
verlassen	2.41	1.23	5.32	2.28
verliebt	8.57	0.74	7.06	2.14
vermodert	3.17	1.25	4.77	2.10
verraten	2.65	1.07	5.82	1.59
verreckt	2.00	1.16	6.89	1.75
verrucht	3.94	1.69	5.15	1.84
verrückt	4.62	1.65	5.62	1.91
verschlafen	4.38	1.07	2.65	1.69
verschmitzt	5.94	1.43	4.91	1.54
verschreckt	3.23	0.97	6.46	1.72
verschwenderisch	3.31	1.28	4.91	2.01

verschwiegen	5.46	1.62	2.91	1.40
versonnen	5.26	1.31	3.03	1.62
verspielt	6.31	1.41	4.77	2.02
versteinert	3.91	1.25	4.17	1.71
vertrauensselig	5.74	1.72	3.94	1.63
vertrauensvoll	6.89	1.30	2.94	1.78
verträumt	6.57	1.22	3.17	1.81
verwahrlost	2.46	1.07	5.34	2.13
verwegen	4.89	1.76	5.50	2.00
verwöhnt	3.77	1.61	4.46	1.87
vielseitig	6.46	0.92	3.69	1.88
vital	7.20	1.11	4.71	2.20
vorwitzig	4.49	1.42	5.00	1.69
wach	6.66	1.43	4.00	2.35
wahnsinnig	3.63	1.99	6.60	1.67
wandlungsfähig	6.11	1.16	4.37	1.59
wankelmütig	3.54	1.12	5.23	1.75
weibisch	3.49	1.36	4.69	2.13
weiblich	6.74	1.29	4.17	2.19
weise	6.91	1.42	2.74	1.67
weitschweifig	4.29	1.20	3.77	2.07
weltlich	5.57	1.04	3.69	1.69
wesentlich	5.26	1.27	3.03	1.75
widerlich	2.14	0.88	6.43	1.54
widerspenstig	3.74	1.38	5.35	2.00
wild	5.89	1.55	6.63	1.78
willig	4.80	1.66	5.23	2.00
wissbegierig	6.37	1.55	4.71	2.07
witzig	7.43	1.33	5.43	1.74
würdevoll	6.71	1.15	3.06	1.63
wütend	2.69	1.05	6.86	1.72
zaghaft	4.37	1.21	3.66	1.88
zahm	5.77	1.17	2.49	1.40
zartbesaitet	4.23	1.31	4.20	1.47
zärtlich	7.94	1.11	4.51	2.32
zerfetzt	2.51	1.17	6.89	1.66
zerfressen	2.43	1.24	5.91	2.11
zerschmettert	2.80	1.26	6.03	1.64
zerstreut	4.31	1.28	4.40	2.25
zimperlich	3.60	1.17	4.49	2.09
zufrieden	7.89	1.11	2.37	1.66
zugeknöpft	3.69	1.28	4.11	1.95
zurückhaltend	5.20	1.23	3.00	1.50
zusammenhanglos	4.17	0.86	3.51	1.80
zwanghaft	2.77	0.88	5.80	1.88
zweifelhaft	3.57	0.95	4.66	1.83

Example of the surprise free recall tests used in the EEG study described in chapter 2 and the fMRI study described in chapter 3. Recall of word categories was randomized for serial order across participants.

Datum: ……. **VPn: …….**

Liebe Versuchsteilnehmerin, lieber Versuchsteilnehmer,

Während des Experiments wurde Ihnen eine Reihe von Wörtern dargeboten, die Sie still lesen sollten. Bitte versuchen Sie sich jetzt an so viele Wörter wie möglich zu erinnern. Versuchen Sie dabei bitte anzugeben, wie angenehm oder unangenehm oder neutral Sie das zu erinnernde Wort empfinden.

Unangenehm:

Neutral:

Angenehm:

Vielen herzlichen Dank!