Electrophysiological Investigations of Attentional Mechanisms Governing Emotional Information Processing

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Human behavior flows from three main sources:

desire, emotion, and knowledge.

– Plato –

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General Introduction

We experience a range of emotions in everyday life, such as joy, sadness, and anger. These affective experiences influence our attention, memory, and judgments. The limbic system, a neural system consisting of various cortical and subcortical brain structures, is responsible for the modulation of emotional responses in both humans and animals (e.g., Hariri, Bookheimer, & Mazziotta, 2000), though other brain areas, such as the prefrontal cortex, are also involved in emotion processing (e.g., Damasio, 1998). In the past, emotion and cognition have been viewed and treated as separate domains. But over the last decades the relationship between emotion and cognition has received increased research interest in the field of cognitive neuroscience, showing that both domains share common brain structures and interact in their influence on behavior (LeDoux, 1996).

Emotions are best characterized in two orthogonal dimensions – *valence* and *arousal*. The valence dimension refers to the hedonic quality of the affective experience and ranges from positive to negative (pleasure-displeasure continuum). The arousal dimension refers to the perception (i.e. subjective experience) of arousal associated with the affective experience and ranges from calm to exciting (activation-deactivation continuum). Thus, affective experiences can be characterized in a two-dimensional space, as varying degrees of the valence and arousal dimension (e.g., Lang, Bradley, & Cuthbert, 1998; Posner, Russel, & Peterson, 2005; Russel, 1980).

Affective experiences influence information processing, such as perception, attention, and memory. Sensory information processing in humans refers to how people perceive, store, retrieve, and utilize information, and it entails automatic and controlled processing modes. Controlled processing is limited in capacity, it requires attention, and is usually involved in new, unknown situations and tasks. In contrast, automatic processing is not limited in capacity, it does not require attention, and it is usually involved in familiar situations and tasks (Shiffrin & Schneider, 1977; Schneider & Shiffrin, 1977). Attention is a fundamental part of information processing and refers to the selective allocation of processing resources on one aspect of the environment, while ignoring others. This is necessary for selecting relevant and meaningful information for further processing, while inhibiting distracting, irrelevant information to avoid cognitive overload (e.g., Desimone & Duncan, 1995). Posner and Boies (1971) distinguish between three components of attention. The first is alertness (arousal), which is the ability to maintain attention to perform long and boring tasks. Selectivity, the second component, refers to the ability to select one type of information while ignoring others. The third component is processing capacity, which concerns the competition between different types of information for limited central processing capacity.

Attention thus determines what information will be encoded, and to optimize selection, humans usually rely on past experiences. Consequently, attention and memory are closely connected with each other, both influencing each other in a reciprocal manner (for a review see Chun & Turk-Browne, 2007). Memory is the ability to store and recall previously learned information. Generally, researchers distinguish between several distinct memory systems: working memory, short-term memory, and long-term memory. Working memory lasts for a few seconds or minutes and is involved in moment-to-moment monitoring, on-line processing, and in the maintenance and manipulation of information necessary for complex cognitive tasks (e.g., Baddeley, 1992). Various definitions of short-term memory exist in the literature and also different opinions with regard to the difference between working memory and short-term memory (for an overview see Aben, Stapert, & Blokland, 2012). Here, the definition by McGaugh (1996) will be used, which states that short-term memory develops within a few seconds or minutes and typically lasts for several hours. Long-term memory, on the other hand, relies on the consolidation of a newly formed memory trace and is relatively permanent. Unlike working memory, short-term and long-term memory preserve information off-line to employ it further when needed (e.g., Izquierdo, Medina, Vianna, Izquierdo, & Barros, 1999; McGaugh, 1966).

The influence of emotions on cognitive functions has been studied extensively in clinical populations. Affective disorders, such as anxiety, depression, and posttraumatic stress disorder, are characterized (1) by an attentional bias for negative and threatening stimuli (e.g., Gotlib, Krasnoperova, Neubauer Yue, & Joormann, 2004; MacLeod, Mathews, & Tata, 1986), (2) by increased susceptibility to emotional distraction (e.g., Schweizer & Dalgleish, 2011; Wang et al., 2008), and (3) by a memory bias for negative and threatening information (e.g., Coles & Heimberg, 2002; Watkins, Mathews, Williamson, & Fuller, 1992). Emotion-cognition interactions are not only influenced by psychopathology, but also by individual differences in personality traits (e.g., Rusting, 1998). Personality and psychopathology are increasingly recognized as linked domains, although the precise nature of the impact of personality in the development of psychopathology is not fully understood (e.g.., Bijttebier, Beck, Claes, & Vandereycken, 2009; Clark, 2005; Widiger & Trull, 1992). Understanding the (neural) mechanisms of how emotions influence the allocation of attention and how these emotion-attention interactions influence other cognitive processes, such as memory for instance, is important, as the occurrence of these effects leads to a detrimental effect on behavior in clinical populations.

The current thesis has two objectives: (1) to investigate attentional mechanisms in the visual perception of and memory for emotional events and (2) to examine the influence of individual differences in positive and negative emotionality on emotional attention and memory. To achieve these aims, we performed a literature review examining controlled and automatic mechanisms underlying emotional influences on attention and memory (Chapter 1), a behavioral study to investigate individual differences in positive and negative emotionality underlying controlled processes in emotional information processing (Chapter 2), and a series of electrophysiological experiments to examine (individual differences in emotional reactivity underlying) attentional mechanisms in the visual perception of emotional events (Chapter 3) and in the memory benefit for emotional events (Chapter 4), respectively. Finally, we aimed to clarify the functional significance of an electrocortical component that has been linked to memory retrieval by examining the contribution of controlled elaboration processes (Chapter 5).

Chapter 1

Attentional Mechanisms in the Visual Perception of and Memory for Emotional Events

Emotions or emotional arousal, respectively, influence what we attend to in our surroundings, thereby enhancing memory in favor of emotional events. There is an ongoing debate in the literature regarding the automaticity of emotional modualtions on sensory information processing. Do we remember emotional events better than neutral events because they are associated with increased attention and elaboration during encoding or do emotions exert their influence on perception, attention, and memory independent of attentional resources? Emotion-attention interactions and their impact on memory for emotional events have been studied extensively. This review summarizes and discusses the influence of emotions on attention and memory and reviews the evidence for automatic and controlled processes in emotional information processing.

This literature review starts with a discussion of emotional influences on attention along with an overview of the brain structures and electrophysiological correlates involved in emotional attention and then reviews the findings regarding the automaticity of attention allocation to emotional stimuli. Then follows an overview of emotional influences on memory, together with the neurobiological findings and a discussion of attentional mechanisms underlying the memory benefit for emotional events. Next, individual differences in emotional attention and memory are discussed, using a neuroscientifc framework of personality. Lastly, the aims of the current thesis are presented and an overview of the following chapters is given.

1. The Influence of Emotion on Attention

Emotions influence the allocation of attentional resources through bottom-up and top-down mechanisms. Emotional stimuli can be processed even under conditions of limited attention (e.g. Pessoa, 2005) or without awareness (e.g., Morris, Öhman, & Dolan, 1998). Stimuli of emotional and evolutionary relevance, like snakes for example, are detected faster and they are more likely to be processed when attention is limited than neutral or positive stimuli, thereby biasing attentional allocation based on physical saliency of the stimulus (bottom-up; e.g., Öhman, & Mineka, 2001). This bottom-up modulation of attention (i.e. exogenous attention) by emotion can be further influenced by top-down mechanisms, such as task goals and reward contingencies (i.e. endogenous attention). That is, emotional cues can be used endogenously to direct visual attention (e.g., Mohanty, Egner, Monti, & Mesulam, 2009; Mohanty, & Sussman, 2013; Yantis, 1993). The notion that emotions modulate the allocation of attentional resources is also referred to as *motivated attention* (Lang, Bradley, & Cuthbert, 1997), *natural selective attention* (Bradley, 2009), or *emotional attention* (Vuilleumier, 2005).

Attentional biases for emotional stimuli have been observed in numerous studies using modified attentional tasks, including the emotional Stroop task (e.g., Williams, Mathews, & MacLeod, 1996), the attentional blink task (e.g., Anderson, 2005; Smith, Most, Newsome, & Zald, 2006), and the spatial orienting task (e.g., Fox, Russo, Bowles, & Dutton, 2001; Stormark, Nordby, & Hugdahl, 1995). Current mood states have also been linked to attentional biases in visual processing. Attention is more readily focused on negative or threatening information when one is in an anxious mood (MacLeod & Mathews, 1988) and on positive or rewarding stimuli when one is happy (Tamir & Robinson, 2007). It has been hypothesized that attentional biases are driven by the valence dimension that prioritizes the processing of negative stimuli or danger signals, but not of positive stimuli, since the detection of negative stimuli (Pratto & John, 1991) or threat-related stimuli (Öhman, Flykt, & Esteves, 2001) is important for survival. Although several studies have shown that negative stimuli capture attention more readily than neutral stimuli (e.g., Anderson, 2003; Öhman et al., 2001; Okon-Singer, Tzelgov, & Henik, 2007) and that also positive stimuli are associated with increased attentional biases relative to neutral stimuli (for a meta-analysis see Pool, Brosch, Delplanque, & Sander, 2016), it is still relatively unknown whether the valence or arousal dimension of emotional events contributes to the attentional biases. While some studies observed increased attention allocation towards negative and threatening stimuli, relative to neutral and positive stimuli (e.g., Fox et al., 2001; Pourtois, Grandjean, Sander, & Vuilleumier, 2004; Pratto & John, 1991), other studies failed to find differences between affective stimuli in the allocation of attention (e.g., Brosch, Sander, Pourtois, & Scherer, 2008; Smith, Cooter, Levy, & Zald, 2007). Since the majority of studies compared high-arousing emotional stimuli with neutral stimuli, which are low in arousal, it is possible that the attentional biases are due to differences in arousal value of the stimulus rather than the affective content. Studies examining the combined effects of valence and arousal in attentional modulations rather support the notion that attentional biases are driven by the arousal dimension (Buodo, Sarlo, & Palomba, 2002; Schimmack, 2005; Vogt, De Houwer, Koster, Van Damme, & Crombez, 2008), while another study observed an influence of arousal level on valence effects in visual attention. Specifically, attentional biases were enhanced for arousing negative relative to positive high-arousal stimuli, while the opposite pattern was observed for low-arousal emotional stimuli (Fernandes, Koji, Dixon, & Aquino, 2011).

It is important to note that emotions not only influence what is attended to but they also influence the focus of attention. Alterations in the attentional breadth have been related to the broadening or narrowing of the attentional spotlight (LaBerge, 1983; Posner, Snyder, & Davidson, 1980). Easterbrook's (1959) cue-utilization hypothesis proposes that emotional arousal associated with negative stimuli (e.g., stress) leads to narrowing of attention. According to this view, when a cue elicits arousal the attentional narrowing occurs as a result from attentional shifts away from non-arousing cues. On the contrary, positive emotions have been shown to be associated with a broadening of the attentional breadth (e.g., Derryberry & Tucker, 1994; Fredrickson & Branigan, 2005; Rowe, Hirsh, & Anderson, 2007). Fredrickson (1998, 2001, 2004) proposed a broaden-and-build theory of positive emotions, which suggests that positive emotions, such as joy or love, lead to broadening of attention to the environment to promote one's personal resources. Indeed, several studies have shown that positive affect produces a more global and broadened focus of attention and cognition, whereas negative affect leads to a more local and narrow focus of attention and cognition (e.g., Fenske & Eastwoord, 2003; Gasper & Clore, 2002; Huntsinger, 2013). Given the importance of high-arousal motivated positive affect states to biologically important outcomes, it has been suggested that such states would not be associated with attentional and cognitive broadening, but rather with decreases in the breadth of attention (Gable & Harmon-Jones, 2008). Thus, emotional intensity (i.e. arousal) associated with positive and negative affective states should be a predictor of attentional scope (local versus global). Indeed, it has been shown that high-approach motivated (high-arousal) positive affect reduced global attentional focus, whereas low-approach motivated (low-arousal) positive affect increased global attentional focus (Gable & Harmon-Jones, 2008). Further, negative affect low in motivational intensity has been found to cause attentional broadening, whereas high-motivation negative affect (i.e., disgust) narrowed the attentional focus (Gable & Harmon-Jones, 2010). Another study observed that attentional narrowing is only caused by high-arousal negative images, but not by neutral or high-arousal positive images (van Steenbergen, Band, & Hommel, 2011).

Electrophysiological studies further revealed that a manipulated global attentional scope reduces N100 amplitudes towards disgust images (Gable & Harmon-Jones, 2012), as well as appetitive images (Gable & Harmon-Jones, 2011), compared to a manipulated local attentional scope, indicating that a global attentional focus is associated with reduced early attentional processing in visual processing of the disgust and negative images. Further, high-motivational affective states were related to a reduced global attentional scope , while low-motivational affective states did not lead to an enhanced global focus (Liu, Zhang, Zhou, & Wang, 2014). This was reflected by reduced N200 amplitudes and a greater late positive potential for high-motivational relative to low-motivational affective states.

Emotions not only influence the focus of attention, but the focus of attention also influences the affective evaluation of otherwise neutral stimuli. It has been shown that attention has a negative affective impact for otherwise neutral or unattended visual stimuli (abstract patterns and unfamiliar faces) that must be ignored or otherwise inhibited during the performance of a task. That is, stimuli that had to be ignored were evaluated more negatively than attended stimuli (Fenske & Raymond, 2006; Raymond, Fenske, & Tavassoli, 2003; for a review see Kaspar & König, 2012). Hence, not the act of attending, but the active ignoring of the distractor led to its affective devaluation. Moreover, distractor devaluation was generally enhanced when the distractor was located near the target, and it was attenuated when the target was further away (Raymond, Fenske, & Westoby, 2005).

In summary, the allocation of attention can thus be modified by emotional arousal. Attention is more readily captured by and focused on emotionally arousing stimuli. Attentional processes are not only influenced by external emotional cues, but also by internal affective cues, which influence what is attended to and how we attend to our surroundings. Overall, the findings seem to suggest that the arousal dimension of the stimulus, but not the valence dimension, is responsible for the observed attentional biases in visual processing.

1.1 Brain mechanisms for affective influences on attention

Studies examining brain activity associated with emotional attention have provided valuable insights into the underlying mechanisms on how emotions influence attentional processes. According to the *biased competition model* of visual attention (Desimone & Duncan, 1995), which is illustrated in Figure 1, when multiple stimuli constitute a visual scene, there is a competition among those stimuli for neural representation in the visual cortex due to limited processing capacities of the visual system. The competition among the stimuli can be biased either by sensory-driven bottom-up mechanisms that originate in the visual cortex, such as stimulus salience (e.g., color or luminance contrast of the stimulus), or by top-down feedback mechanisms, such as directed attentions, that originate outside the visual cortex. The stimulus that wins the competition gains access to memory and motor system and thereby influences ongoing behavior.

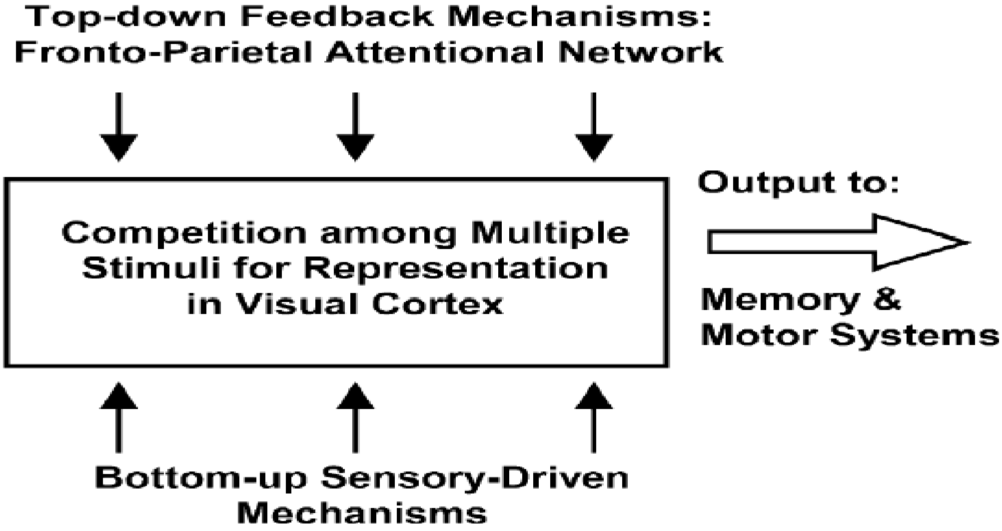


Figure 1. Biased competition model of visual attention. Figure reused with permission from Pessoa et al. (2002) Elsevier.

Research has shown that selective attention enhances sensory processes through modulatory mechanisms on early cortical pathways in the fronto-parietal network (e.g., Kastner & Ungerleider, 2000; Pessoa, Kastner, & Ungerleider, 2002). Emotion and attention influence visual processing in the visual cortex, but these influences originate from different brain regions: while the amygdala is involved in the neural circuitry for emotion and emotional learning, the fronto-parietal circuitry is involved in attentional modulation (for reviews see Pourtois, Schettino, & Vuilleumier, 2013; Vuilleumier, 2005; Vuilleumier & Driver, 2007; Vuilleumier & Huang; 2009). Two mechanisms underlie the increased attentional salience of emotional stimuli: the dorsal attention network (DAN) and the ventral attention network (VAN). Several dorsal brain areas form the DAN, including dorsolateral prefrontal regions that are important for attentional executive control (e.g., frontal eye fields and (pre)motor areas) and the superior parietal cortex, a sensory cortex crucial for the stimulus-driven control of attention. The DAN is involved in the control of visual-spatial attention via top-down mechanisms. Brain regions such as the ventromedial frontal cortex, involved in emotion regulation, and the temporo-parietal junction, comprise the VAN. This attentional network is also involved in stimulus-driven control by directing the attentional focus towards relevant sensory stimuli that are out the focus of attention and it interrupts ongoing behavior when required (Corbetta & Shulman, 2002). Research has shown that peripheral distractors increase activity in the DAN relative to central distractors (Carretié et al., 2013) and that DAN and VAN activity is enhanced in response to emotional distraction (for a review see Carretié, 2014). Figure 2 illustrates the VAN and DAN in their meditational effects between attentional and emotional control. The amygdala is directly connected to the visual cortex. Consequently, visual perception and processing of emotional stimuli is in part enhanced by amygdala activation (e.g., Pourtois et al., 2013; Vuilleumier, 2015).

Event-related potentials (ERP) studies have identified several ERP components linked to early attentional processes in visual processing (i.e., P100, N100), an early posterior negativity linked to selective attention, and several ERP components associated with later stages of stimulus processing, such as increased and sustained attention and stimulus evaluation (i.e., P300, late positive potential, positive slow waves) (Olofsson, Nordin, Sequeira, & Polich, 2008). Several studies have shown that the aforementioned ERP components are enhanced in response to emotional stimuli relative to neutral stimuli, reflecting greater attentional biases for emotional stimuli. More specifically, the early ERP components (P100, N100) have been shown to be influenced by the valence dimension of the stimulus, with negative stimuli eliciting increased amplitudes compared to positive and neutral stimuli, while arousal exerts its influence on later components (i.e., early posterior negativity, P300, late positive potential, positive slow waves) (for reviews see Olofsson et al., 2008; Schupp, Flaisch, Stockburger, & Junghöfer, 2006).

In conclusion, emotion modulates the allocation of attentional via bottom-up and top-down mechanisms that are mediated by the DAN and VAN. Further, ERP studies have shown a differential modulation of early and late ERP waveforms between emotional and neutral stimuli during visual attention.

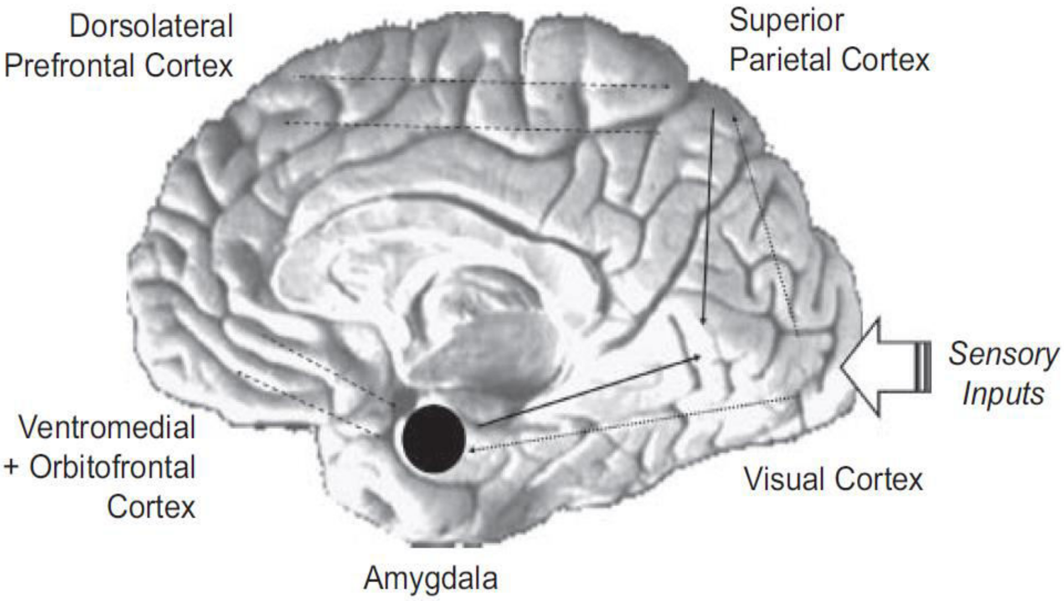


Figure 2. Illustration of the dorsal and ventral attention network that mediate the interaction between attentional and emotional control. Figure reused with permission from Vuilleumier and Huang (2009) SAGE Publishing.

1.2. Exogenous attentional mechanisms in emotional processing

The prioritized allocation of attentional resources towards emotional stimuli has been assumed to reflect automatic processes, independent of attentional resources during visual perception (e.g., Pratto & John, 1991; Williams et al., 1996). In comparison to the vast amount of research examining the neural correlates of endogenous (voluntary) attention to emotional stimuli, exogenous (automatic) attentional mechanisms in affective visual processing have been examined less extensively (Carretié, 2014). Exogenous attention is examined through the use of *directed attention tasks* (MacNamara, Kappenman, Black, Bress, & Hajcak, 2013), also named *concurrent but distinct target-distractor* (CDTD) *paradigms* (Carretié, 2014). Studies that employ affective versions of the attentional blink task (e.g., Anderson, 2005) or the spatial orienting task (e.g., Fox et al., 2001), for instance, in which targets and distractors are presented with a temporo-spatial distance, provide a measure of automatic engagement to the primary target stimulus as a result of prior exposure to the emotional stimulus (Carretié, 2014). In contrast, directed attention tasks concurrently present the emotional distractor stimulus with the target stimulus and participants are instructed to focusing their attention on the target stimuli and to ignore the emotional distracting stimuli. Thus, directed attention tasks are a useful tool for studying exogenous attentions, since they provide information with respect to preattention, reorienting, and enhanced sensory processing (Carretié, 2014).

Inconsistent results have been reported regarding the automaticity of attention allocation to emotional stimuli. A number of fMRI studies have shown that directed attention does not impair amydala activity (e.g., Anderson, Christoff, Panitz, De Rosa, & Gabrieli, 2003; Fichtenholz et al., 2004; Vuilleumier, Armony, Driver, & Dolan, 2001), which suggests that attention allocation towards emotional stimuli occurs rather automatic and independent of the available attentional resources. However, this view has been challenged by other studies reporting lacking amydala activity in response to emotional distractor stimuli when attention is directed to an attentional demanding primary task (Pessoa, McKenna, Gutierrez, & Ungerleider, 2002; Pessoa, Padmala, & Morland, 2005; Silvert et al., 2007). Generally, it has been noted that the effects of load on distractor processing depend crucially on the type of mental processing that is loaded. According to Lavie's load theory of attention and cognitive control (e.g., Lavie, 2005, 2010), the ability to focus attention and to ignore task-irrelevant distractors is enhanced under conditions of high perceptual load. High-load on frontal (executive) cognitive control functions, such as working memory, which renders them unavailable to actively maintain stimulus-processing priorities throughout task performance, increases interference by and processing of task-irrelevant distractors. In concordance, it has been observed that behavioral performance (e.g., accuracy, reaction time) is better in low-load conditions relative to high-load conditions (e.g., Gupta, Hur, & Lavie, 2016; Gupta & Srinivasan, 2015).

The influence of directed attention on exogenous attention to emotional stimuli has also been examined by ERP studies. Emotional effects have been reported to be absent for the EPN and LPP when attention is directed away from the emotional stimulus (e.g., De Cesarei, Codispoti, & Schupp, 2009; Eimer, Holmes, & McGlone, 2003; Holmes, Kiss, & Eimer, 2006; MacNamara & Hajac, 2009) or preserved but reduced in magnitude (Hajcak, Dunning, & Foti, 2007; Sand & Wiens, 2011; Wiens, Sand, Norberg, & Andersson, 2011). Using emotional words as distractors, instead of images, during the concurrent performance of a digit categorization task, it has been observed that the N100 amplitude, a component involved in early, automatic attentional processes, is greater is response to positive compared to neutral and negative distractor words. No differences in N100 amplitudes have been observed between neutral and negative distractor words

(Hinojosa et al., 2015). A recent study examined valence-arousal interactions in exogenous attention to emotional stimuli (Wiens & Syrjänen, 2013). The linear influence of arousal value on EPNs decreased when attention was directed away from the emotional distractor stimulus, while the linear effect of arousal on LPP amplitudes decreased only for positive images but not negative images. Employing an emotional primary task, it has further been shown that negative images elicit increased LPP amplitudes relative neutral images, regardless of the affective content of the distractor images (MacNamara & Hajcak, 2009, 2010). Correspondingly, ERP studies examining spatial attention in emotional face processing observed that when spatial attention is directed away from the faces, ERP waveforms elicited by the faces (P200, N200, N170) no longer show enhanced processing of emotional faces relative to neutral faces (Holmes, Kiss, & Eimer, 2006; Holmes, Vuilleumier, & Eimer, 2003).

Evidence suggests that exogenous attentional mechanisms to emotional stimuli are different for tasks that physically separate the emotional distractors from the neutral primary task and for tasks that overlay the emotional distractors and the primary task. Emotional distractors presented at fixation elicit larger ERP amplitudes than emotional stimuli presented in the periphery (Carretié et al., 2013; De Cesarei et al., 2009). In concordance, EPNs have been noted to be enhanced for negative relative to neutral stimuli when the primary task and emotional scenes were presented concurrently but physically separate, while the LPP amplitudes has been found to be greater for negative than neutral images when the primary tasks was overlaid on the emotional distractor, regardless of stimulus material (scenes vs. figures) (Nordström & Wiens, 2012). Studies that superimposed the primary task on the emotional distractor stimuli showed that negative distractor stimuli elicit greater EPNs and LPP amplitudes than neutral distractor stimuli (Schönwald & Müller, 2014) and that positive images no longer elicit enhanced LPP amplitudes relative to negative images when attention was focused on the primary task (Wangelin, Löw, McTeague, Bradley, & Lang, 2011). Using steady-state visual evoked potentials to examine the influence of task-irrelevant emotional distractors on visual processing of task-relevant neutral stimuli (i.e., random dot kinematograms), it has been observed that the amplitude of steady-state visual evoked potentials elicited by kinematograms is reduced on trials in which the kinematograms are sumperimposed on emotional images, relative to neutral images (e.g., Attar, Andersen, & Müller, 2010; Dweese, Müller, & Keil, 2016; Müller, Andersen, & Keil, 2008; Schönwald & Müller, 2014). This indicates that during trials with negative or positive images, less attentional resources are allocated to the primary foreground task, an effect that was further paralleled by reduced performance in the primary task when emotional distractors were presented. These effects have further been found to be unrelated to the load of the primary task (Attar & Müller, 2012). In contrast, ERP studies observed that when attentional resources are focused on a more difficult attention task, emotional images fail to elicit an emotion modulation of the EPN relative to neutral images, especially under conditions of high load (Schupp, Stockburger, Bublatzky, Junghöfer, Weike, & Hamm, 2007). Yet, when the attention task taps the auditory modality rather than the visual modality, no effect of attention on the emotion modulation of the EPN has been observed - regardless of task difficulty (Schupp, Stockburger, Bublatzky, Junghöfer, Weike, & Hamm, 2008). Examining the influence of load on emotional face processing, it has further been observed that angry faces elicit larger EPNs and N170 amplitudes than happy faces under low load, but not under high load conditions, while no effects have been observed for the LPP (Müller-Bardorff et al., 2016).

Overall, the studies reviewed in this section provide inconsistent results with regard to the automaticity of the allocation of attentional resources towards emotional stimuli. Residual attention to emotional stimuli is especially prominent when emotional distractors are presented at fixation, instead of in the periphery. It is possible that these inconsistencies are due to differences in attentional load of the primary task across studies. Although the majority of studies compared the influence of neutral and negative distractor stimuli, while a lesser part also included positive distractor stimuli, the results suggest that negative and positive distractor stimuli show increased capture of exogenous attention than neutral stimuli. Since few studies examined valence-arousal interactions in exogenous attention to emotional stimuli (Müller-Bardorff et al., 2016; Wiens & Syrjänen, 2013), it remains to be clarified whether the enhanced attentional caputure by emotional stimuli is the result of the arousal dimension of the distractor stimulus or whether the enhanced capacity to capture attention is the result of the combined influence of the valence and arousal dimension. Preliminary evidence further suggests that emotional distractors capture attention, even when the primary task is emotional itself (MacNamara & Hajcak, 2009, 2010). However, this aspect needs further exploration, since investigations have been restricted to the LPP, confronting neutral and negative valenced target and distractor stimuli.

2. The influence of emotion on memory

Emotional arousal not only exerts its influence during encoding, but also influences the likelihood of memory consolidation. This *emotional memory enhancement* effect of emotion has been demonstrated in a great number of studies, using different paradigms and stimuli such as words, images, and narrative stories Studies have shown that the emotional memory enhancement effect increases after longer delays (e.g., LaBar & Phelps, 1998). This observation is in line with the suggestion that emotionally arousing memories are more likely to consolidate into a stable and permanent memory trace, whereas memories for neutral or low-arousing events are more likely to be disrupted (Kensinger, 2004).

Few studies have examined the relative contribution of emotional valence and arousal underlying the emotional memory enhancement effect. The results provide conflicting results regarding the influence of arousal value (high vs. low) on recognition memory performance. On the one hand, memory performance has been found to be impaired for emotional stimuli low in arousal relative to medium or high-arousal emotional stimuli, but better than neutral stimuli (Ochsner, 2000; Schaefer, Pottage, & Rickart, 2011; Steinmetz & Kensinger, 2009; Xu, Zhang, Li, & Guo, 2015). On the other hand, other studies failed to find an influence of arousal level on recognition memory performance (Kaestner & Polich, 2011; Van Strien, Langeslag, Strekalova, Gootjes, & Franken, 2009). The reviewed studies further report inconsistent results regarding the influence of affective content (positive vs. negative) on the memory benefit for emotional stimuli high and low in arousal. Memory performance has been found to be enhanced for positive/high-arousal stimuli relative to negative/high-arousal stimuli, but similar for emotional stimuli low in arousal (Gomes, Brainerd, & Stein, 2013; Xu et al., 2015), whereas another study found that emotional memory was influenced by the arousal dimension but not by the valence dimension of the stimulus (Bradley, Greenwald, Petry, & Lang, 1992). Further, positive/low-arousal images have been shown to be associated with similar recognition performance relative to neutral images, while memory performance was enhanced for negative/low-arousal images relative to neutral images (Steinmetz & Kensinger, 2009).

Emotional arousal not only enhances memory, but it can also impair memory. Attentional narrowing associated with negative mood states and stimuli (e.g., Easterbrook, 1959) has been linked to enhanced memory for emotional, central details and impaired memory for neutral, peripheral details of an emotional event (e.g., Christianson & Loftus, 1991). This attentional narrowing is consistent with research on the *weapon focus* in eyewitness memory, showing that arousing objects (e.g., a gun) capture attention and therefore enhance memory for the object at the expense of other details (e.g., an accurate description of the perpetrator) (e.g., Loftus, Loftus, & Messo, 1987; for reviews see Christianson, 1992; Kramer, Buckhout, & Eugenio, 1990). Indeed, research has shown that memory narrowing occurs more frequently for negative than positive experiences (e.g., Berntsen, 2002; for a review see Kensinger, 2009).

Studies investigating the contribution of arousal, elicited by emotional stimuli, stress, or through the administration of stress hormones, on information processing have produced mixed results: whereas some studies observed support for the notion that arousal enhances perception and memory, other studies either observed no effect or impaired perception and memory for arousing stimuli (for a review see Mather, 2007). Mather and Sutherland (2011) developed the "*Arousal-Biased Competition*" (ABC) model to account for the discrepancies in the literature. According to this model, when initially processing information, arousal (brought out by external stimuli, thoughts, or stress hormones) influences competition between different stimuli for mental resources (i.e. selective attention), increasing processing of high priority, goal-relevant stimuli and decreasing processing of low priority, goal-irrelevant stimuli. This competition starts during perception and persists into long-term memory consolidation. Subsequently, arousal enhances memory consolidation for goal-relevant stimuli – regardless of the arousal level (high vs. low) of the stimuli (i.e. regardless of whether the stimulus has priority because of its bottom-up attention grabbing nature or because of top-down goals). Furthermore, the ABC model hypothesizes that arousal experienced during encoding biases memory consolidation in support of high priority information from the event, while weakening memory consolidation of low priority information from that event. Priority is assumed to be determined by bottom-up perceptual salience and top-down relevance. In concordance with the predictions of the ABC model, a recent fMRI study has observed that under conditions of arousal (receiving a shock), brain activation related to the processing of a salient stimulus was increased, while brain activation related to the processing of a non-salient stimulus was suppressed (Lee, Sakai, Cheng, Velasco, & Mather, 2014). In concordance, negative arousing trials were found to be associated with increased recall of high-salience stimuli, while recall of low-salience letters was not affected by arousal (Lee, Itti, & Mather, 2012; Sutherland & Mather, 2012). Further, inducing arousal by means of a video comedy after the encoding of high and low arousing positive and negative words influences subsequent recognition memory (Nielson & Lorber, 2009). More specifically, the group of participants that viewed the arousing video after encoding showed better recognition for previously seen words one week later, than participants that viewed a neutral control video. Yet, this effect was not further modulated by the emotional content of the words. Thus, these findings suggest that arousal (but not necessarily the stimulus arousal) improves memory consolidation.

In conclusion, emotional stimuli are remembered better than neutral stimuli. Nevertheless, the relative contribution of valence and arousal on the emotional memory enhancement effect remains to be clarified as the results are inconsistent in the literature. Studies are needed that examine the influence of time delay (i.e. short-term vs. long-term memory) on the memory benefit for low-arousal and high-arousal emotional stimuli to clarify whether low-arousing emotional events are indeed more prone to disruption relative to arousing emotional events (Kensinger, 2004).

2.1 Brain mechanisms for affective influences on memory

To assess the neurophysiological correlates of memory performance, studies have measured the brain activity either at encoding or during memory retrieval. Studies that measure brain activity at encoding examine differences in neural activity during encoding as a function of subsequent memory performance. This contrast between remembered and forgotten items is also known as the *Difference due to memory (Dm)* index. The Dm index is assumed to reflect successful encoding processes during the initial study phase. ERP studies that measure brain activity during memory retrieval compare neural responses to correctly classified old items (hits) and correctly identified new items (correct rejections), while fMRI studies contrast responses to successful retrieval of old items to unsuccessful retrieval trials (misses) (e.g., Friedman & Johnson, 2000; LaBar & Cabeza, 2006; Paller, Kutas, & Mayes, 1987).

Previous research has identified the amygdala as an important brain structure in encoding and in the consolidation of emotional arousing events (e.g., McGaugh, 2004), which influences memory-storage processes in several brain regions, such as the hippocampus, striatum, and sensory neocortex (Cahill & McgGaugh, 1998). Brain imaging studies have shown that emotional events increase memory by modulating activity in the medial-temporal lobe (MTL) and the prefrontal cortex (PFC). Different mechanisms have been related to how the amygdala mediates the modulatory effect of emotion on activity in the MTL and PFC. The interaction of the amygdala with the MTL is assumed to reflect a basic, direct bottom-up mechanism, whereas the PFC is assumed to have a more indirect and mediating influence (i.e. top-down mechanism) underlying the memory benefit for emotional events by enhancing attentional processes, working memory, and memory strategies, for instance (e.g., Dolcos, Denkova, & Dolcos, 2012; Hamann, 2001; LaBar & Cabeza, 2006). fMRI studies examining the influence of arousal-based changes in amygdalar connectivity on successful encoding of emotional stimuli have found that amygdalar connectivity was strengthened in response to high-arousal negative images, relative to low-arousal negative images, while for positive images the arousal level decreased the strength of amygdala efferents. Further, for negative images, arousal led to a more widespread connectivity between other nodes associated with the memory network, while for positive images the effect of arousal was restricted to the amygdala efferents (Steinmetz, Addis, & Kensinger 2010). Looking beyond amygdala-hippocampal interactions, it has been shown that subsequent memory processes for arousing and negative stimuli are related to temporal-occipital brain regions, while the successful encoding of positive and nonarousing images engaged more frontal brain region (e.g., Kensinger & Corkin, 2004; Steinmetz & Kensinger, 2009). As has been noted by the authors, the findings suggest that encoding processes (e.g., sensory vs. elaborative processing) differ based on the affective content of the to-be-remembered material. Figure 3 illustrates the potential arousal-mediated influences of the amygdala on emotional memory.

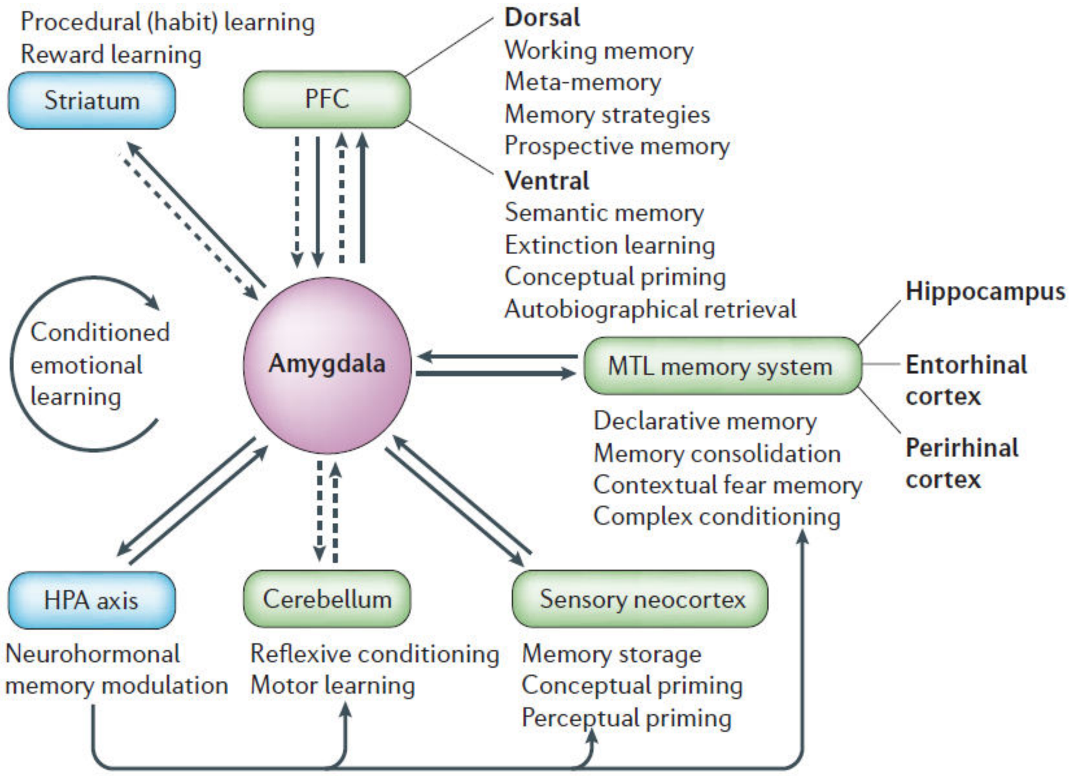


Figure 3. Schematic diagram illustrating the mechanisms by which the amygdala mediates arousal influences on memory. Solid arrows indicate direct connections, dashed arrows indicate indirect connections. Subcortical structures are designated as blue labels. Note: MTL: medial temporal lobe, PFC: prefrontal cortex, HPA: hypothalamic–pituitary–adrenal. Figure reused with permission from LaBar and Cabeza (2006) Nature Publishing Group.

Studies examining electrocortical correlates of memory retrieval have noted that ERPs elicited by old items tend to be more positive than ERPs elicited by new items. Specifically, two ERP old/new effects have been identified: an early old/new effect peaking around 300 - 500 ms and a later old/new effect peaking around 400 - 800 ms. Research has suggested that the earlier aspect of the ERP old /new effect (300–500 ms) may be related to familiarity whereas the later aspect (400–800 ms) may be related to recollection. The early old/new effect is more frontally distributed, whereas the later old/new effect is distributed over centro-parietal sites (Curran & Cleary, 2003; Friedman & Johnson, 2000; Rugg, Schloerscheidt, & Mark, 1998). Some studies of memory have also noted a late posterior negativity component (LPN, 800-1200 ms) - an ERP component that is sensitive to old/new differences and which has been linked to stimulus retrieval processes (Johansson & Mecklinger; 2003; Mecklinger, Rosburg, & Johansson, 2016). ERP studies investigating the old/new effect in memory retrieval require participants to make old/new judgments or remember/know judgments. The remember/know technique allows for an assessment of the memory quality for stimuli that have been recognized (Gardiner, 1988; Tulving, 1985). This technique has been used to dissociate between recollection and familiarity in the ERP old/new effects. Recollection is assumed to be a slow process, which requires attention, while familiarity assessments are assumed to be fast and automatic (Yonelinas, 2002). A *remember* judgment indicates conscious recollection of the previously presented stimulus, including contextual details. A *know* judgment refers to a feeling of familiarity for the previously presented stimulus without knowledge of more detailed and contextual information of the stimulus presentation. At encoding as well as during memory retrieval, correctly recognized stimuli associated with a remember judgment have been shown to elicit a greater old/new effect at parietal sites than correctly recognized stimuli associated with a know judgment (e.g., Friedman & Johnson, 2000; Friedman & Trott, 2000; Rugg et al., 1998). Further, ERPs elicited by stimuli that were later associated with a remember judgment showed greater positivity from 400–1000 ms during encoding than ERPs elicited by stimuli that were forgotten. In contrast, ERP amplitudes elicited by stimuli with a know judgment did not differ from ERPs elicited by stimuli that were forgotten (Friedman & Trott, 2000).

In a free recall task, greater ERPs (400–600 ms) at centro-parietal sites during encoding have been shown to be related to enhanced memory for emotional images relative to neutral images. Further, the old/new effect for emotional stimuli occurred faster (400–600 ms) than the old/new effect for neutral stimuli (600–800 ms), suggesting that emotional stimuli have privileged access to processing resources (Dolcos & Cabeza, 2002). Likewise, in another study a positive correlation emerged between P300 amplitude at parietal sites during affective picture processing and the subsequent recall of emotional slides, irrespective of emotional valence (Palomba, Angrilli, & Mini, 1997). In accordance with the ABC model (Mather & Sutherland, 2011), exposure to stress prior to encoding appears to further enhances processing and memory for unpleasant images relative to neutral images (Weymar, Schwabe, Löw, & Hamm, 2012). This effect was reflected by a significant correlation between the late positive potential (400–800 ms) for unpleasant images obtained during encoding and the number of later recalled unpleasant images in the stressed group, but not in the control group.

ERP studies investigating the electrophysiological correlates of emotional memory retrieval have reported inconsistent results with regard to the modulatory influence of emotion on the ERP old/new effects. Despite the fact that the majority of studies found increased old/new effects for emotional stimuli for the late parietal old/new component, but not for the early frontal old/new component (Johansson, Mecklinger, & Treese, 2004; Maratos, Ellen, & Rugg, 2000; Weymar, Bradley, El-Hinnawi, Lang, 2013; Weymar, Löw, Melzig, & Hamm, 2009), few studies reported greater old/new effects for emotional relative to neutral stimuli for the early frontal and late parietal old/new component (Schaefer et al., 2011; Xu et al., 2015). Other studies reported greater ERP old/new effects for emotional stimuli for the early frontal old/new component but not for the late parietal old/new component (Wang, Wu, Gao, Yang, Wang, & Li, 2013), or null results with regard to both ERP old/new components (Windmann & Kutas, 2001). In addition, the results remain unclear regarding the differential influence of affective content (positive vs. negative) on the ERP old/new effects: while some studies observed no differences in the late parietal ERP old/new effect between negative and positive stimuli (Wang et al., 2013; Weymar et al 2009; Xu et al., 2015), other studies reported a greater early frontal or late parietal ERP old/new effect for negative (Inaba, Nomura, & Ohira, 2005; Johansson et al., 2014; Weymar, Löw, & Hamm, 2011) or positive stimuli (Xu et al., 2015). The majority of the aforementioned studies have generally contrasted neutral nonarousing stimuli with highly arousing positive and negative stimuli. The few number of ERP studies that included low arousing emotional stimuli observed greater early frontal and late parietal ERP old/new effects for high compared to low arousal stimuli (Kaestner & Polich, 2011; Schaefer et al., 2011; Xu et al., 2015), while another study failed to find arousal influences (high vs. low) on the ERP old/new effects (Van Strien et al., 2009).

Remember/know judgments and the corresponding ERP correlates have been shown to be influenced by the affective content of the presented materials during the test phase. Emotional images have been found to be associated with more remember judgments than neutral images, even though the frequency of remember judgments did not differ between negative and positive images (Schaefer et al., 2011; Weymar, Löw, Schwabe, & Hamm, 2010), while another study found that negative images, compared to neutral and positive images, are more frequently associated with remember judgments (Wang, et al., 2013). Know judgments for previously seen images were found to be higher for neutral images than for emotional images (Weymar et al., 2010), whereas other studies failed to find affective influences on know judgments (Schaefer et al., 2011; Wang, et al., 2013). Moreover, research has noted a frontal ERP know/new difference during memory retrieval for emotional images but not neutral images (Schaefer et al., 2011; Wang, et al., 2013). The parietal ERP remember/new difference was found to be larger for emotional images (positive and negative) than for neutral images (Weymar et al., 2010), although other studies either observed parietal remember/new difference for emotional images, but not for neutral images (Schaefer et al., 2011) or no differential impact of affective content on the parietal remember/new difference (Wang, et al., 2013).

Taken together, the studies reviewed in this section indicate that while the amygdala is involved in the memory benefit for emotionally arousing stimuli, prefrontal brain regions involved in controlled and elaborated encoding underlie the memory benefit for low-arousing emotional stimuli (e.g., Kensinger, 2004; Kensinger & Corkin, 2004; Steinmetz & Kensinger, 2009). Correctly remembered emotional stimuli elicit a greater early frontal old/new effect (300–500 ms) and a late parietal old/new effect (500–800 ms) than neutral stimuli, even though research is scarce that investiagtes valence-arousal interactions underlying the memory benefit for emotional stimuli and it yielded inconsistent results across studies. Furthermore, with the exception of a small number of studies (Weymar et al., 2009, 2011), previous ERP studies have mainly studied the influence of emotions on short-term memory performance. Since memory consolidation, the transformation of a new memory trace into long-term memory, is a process that takes hours or days to complete and that depends on the modulation of the hippocampus and related brain circuitries by the amygdala (e.g., Cahill & McGaugh, 1998; Dudai, 2004), more research is needed that examines the memory benefit for emotional stimuli after longer delays.

2.2 Exogenous attentional mechanisms underlying emotional memory

Emotional stimuli are associated with prioritized processing as they capture attention more readily than neutral stimuli. Since the allocation of attention during intial perception and encoding influence memory (e.g., Craik, Govoni, Naveh-Benjamin, & Anderson, 1996), it has been put forward that the memory benefit for emotional stimuli is the result of increased allocation of attention resources during encoding (e.g., Hamann, 2001). Complementing the emotional effects on attention, emotional effects on memory (especially for negative stimuli) are assumed to involve automatic, bottom-up mechanisms and more controlled, top-down mechanisms, i.e., *preattentive processing* and *poststimulus elaboration* (e.g., Christianson, 1992). Whereas preattentive processing is fast, automatic and independent of processing capacities, poststimulus elaboration needs attention, it requires effort, and it is reliant on limited processing resources.

One line of research has examined exogenous attentional mechanisms underlying emotional memory through the use of divided attention tasks by assessing recognition memory performance for concurrently but physically separate presented task-irrelevant emotional and neutral distractor stimuli. Negative spoken distractor words, which were presented during the serial presentation of neutral words that had to be memorized, impaired the recall of the neutral words relative to positive and neutral spoken distractor words (Buchner, Rothermund, Wentura, & Mehl, 2004). Concurrent presentations of affective images with emotional distractors yielded no differential influence of distractor valence on working memory and short-term recognition performance for negative images, whereas working memory (Ziaei, Peira, & Persson, 2014) and short-term memory recognition accuracy (Ziaei, von Hippel, Henry, & Becker, 2015) for positive images was impaired when simultaneously presented with negative distractors relative to neutral distractors. Further, the instruction to ignore the emotional distracters while focusing on the primary image was associated with increased activation in striatal regions (precentral gyrus, the putamen, and the caudate nucleus) and within the left amygdala and these effect were enhanced for emotional relative to neutral distractor images (Ziaei et al., 2014). Another study assessed the influence of emotional arousal on attention and recognition performance (Sharot & Phelps, 2004). In this study, a neutral word was always presented in the center of the screen, while a neutral or negative arousing word was simultaneously in one of the corners of the screen. The results indicated that memory performance, assessed three minutes after the end of the encoding phase, for the central neutral word was unaffected by the words presented in the periphery. After a 24 hour delay, memory performance worsened for neutral peripheral words, but not for arousing peripheral words. Using a letter-identification task, it has further been noted that perceptual load further modulates attentional processes in emotional memory (Gupta & Srinivasan, 2015). Specifically, short-term memory was inhibited for sad but not happy faces presented under high perceptual load, while no differences in recognition performance were observed between sad and happy faces presented under low perceptual load.

Another line of research examined exogenous attentional mechanisms in the memory benefit for emotional by placing the neutral target stimulus over the emotional distractor stimulus, instead of physically separating them. In one study random letter strings were presented on a screen, superimposed on a neutral distractor face (Jenkins, Lavie, & Driver, 2005). Attention was manipulated by the perceptual load of the primary task. In the low-load condition, participants were asked to identify the color of the letter string. In the high-load condition, participants were asked to identify a certain letter in the letter string. Incidental recognition memory for neutral faces was found to be better in the low-load condition compared to the high-load condition. Using the same paradigm, another study presented random letter strings superimposed on a neutral, happy, or sad distractor face (Srinivasan & Gupta, 2010). The results revealed that in low-load conditions, happy distractor faces are recognized better than sad faces in a surprise recognition test, whereas in high-load conditions the opposite pattern was observed. When using negative stimuli that vary in arousal level, divided attention resulted in similar memory performance for neutral and low-arousal negative images, while recall performance remained enhanced for medium and high-arousal negative images (Pottage & Schaefer, 2012).

The aforementioned studies divided attention by using tasks that tapped the same sensorial modality as the distractor stimuli (i.e. visual modality). Other studies have examined the impact of attention on the memory benefit for emotional stimuli by manipulating attentional processing resources for the affective material through the concurrent performance of another task-irrelevant, neutral task (e.g., auditory discrimination task), which is presented in a different sensory modality (e.g. auditory modality) than the emotional distractor stimuli (visual modality). Even though divided attention at encoding has been shown to result in impaired memory performance relative to full attention, the influence of divided attention on the memory enhancement effect for emotional stimuli is less clear. While some studies reported that divided attention at encoding does not differentially affect the emotional memory enhancement effect (Kern, Libkuman, Otani, & Holmes, 2005; Steinmetz, Waring, & Kensinger, 2014; Talmi & McGarry, 2012), other studies observed that divided attention impairs the memory performance for neutral and positive stimuli, but not for negative stimuli (Maddox, Naveh-Benjamin, Old, & Kilb, 2012; Talmi, Schimmack, Paterson, & Moscovitch, 2007). Assessing the influence of emotional arousal on memory for negative and neutral words, it has further been noted that under conditions of divided attention, compared to full attention, the memory benefit for nonarousing negative words is reduced (Clark-Foos & Marsh, 2008) or disappeared (Kensinger & Corkin, 2004).

Finally, other studies examined the influence of poststimulus elaboration on the memory benefit for emotional stimuli. The frequency of spontaneous intrusive recollections for earlier encoded film material has been found to correlate with the number of recalled details, but only for emotional material and not for neutral material (Ferree & Cahill, 2009). Divided attention during the interstimulus interval results in impaired memory performance, but negative images tend to be remembered better than neutral images under conditions of full and divided attention (Steinmetz et al., 2014). Examining the influence of emotional content (negative vs. positive), it has been observed that poststimulus elaboration play a role in the in the recall of negative images, but not in the recall of positive and neutral images (Libkuman, Stabler, & Otani, 2004). These effects were independent of the arousal value (high vs. low). Another study examined the roles of poststimulus elaboration in the memory enhancement effect by having the participants perform the concurrent secondary task either during picture viewing, during the interstimulus interval, or during picture viewing and the interstimulus interval (Migita, Otani, Libkuman, & Sheffert, 2011). In contrast to the results by Libkuman et al. (2004), memory performance for negative images was affected less by postsimulus elaboration compared to positive and neutral images, as negative images were recalled better across conditions. A different set of studies manipulated attentional resources through the use of emotional distractors presented during a maintenance interval to examine attentional processes underlying working memory performance for emotional and neutral target stimuli. One study assessed how task-irrelevant emotional stimuli interfere with working memory performance when the to be remembered material is emotional itself (Jackson, Linden, & Raymond, 2012). Participants encoded two happy or angry faces during each trial. During a maintenance interval a neutral, negative, or positive word was flashed on the screen for three times. Next, a face appeared on the screen and participants were asked to indicate whether they had seen the face before during the trial. Working memory performance for angry faces was found to be better when an emotional (negative or positive) versus a neutral distractor word was presented during a maintenance interval. In contrast, working memory for happy faces was unaffected by distractor valence. Using an emotional word categorization task during the maintenance interval, it was further noted that emotional congruency between face (happy or angry) and word (negative or positive) improved working memory for angry faces but not for happy faces (Jackson, Linden, & Raymond, 2014). fMRI studies have shown that working memory performance for neutral faces is impaired when neutral and negative arousing distractors are presented during a delay and the presentation of distractors deactivated brain regions in the dorsolateral prefrontal cortex that are associated with working memory (e.g., Dolcos, Diaz-Grandados, Wang, & McCarthy, 2008; Dolcos & McCarthy, 2006, Iordan & Dolcos, 2017; Zanto, Clapp, Rubens, Karlsson, & Gazzaley, 2016).

The results of the reviewed studies in this section suggest that emotional, high-arousal stimuli are processed automatically, while controlled and more effortful encoding processes are required for neutral (and positive) stimuli. Since few studies examined the influence of the arousal value (high vs. low) and since those studies focused on the comparison between neutral and negative stimuli the combined effects of valence and arousal remain to be investigated. This is especially important since it has been suggested the emotional memory enhancement effect for high-arousal emotional stimuli is driven by different processes than the memory enhancement effect for low-arousal emotional stimuli: while the memory benefit for high-arousing emotional stimuli is assumed to be driven by automatic attentional processes, the memory benefit for low-arousing emotional stimuli is assumed to be driven by controlled and conscious encoding strategies (Kensinger, 2004). Preliminary evidence supports this notion by showing that the memory enhancement effect for negative nonarousing stimuli disappears when performing a concurrent task (Kensinger & Corkin, 2004; Pottage & Schaefer, 2012). Further, studies are lacking that have examined the neurophysiological correlates of exogenous attentional mechanisms underlying emotional memory.

3. Individual Differences in Emotional Attention and Memory

Individuals preferentially process emotional stimuli that are congruent with their personality traits (trait-congruency hypothesis; e.g., Rusting, 1998). Theories on the neuroscience of personality view underlying differences in neurobiological systems, responsible for appetitive (approach) and aversive (avoidance) motivation as the causal basis of personality traits. The groundwork for this theoretical framework has been made by Gray's reinforcement sensitivity theory of personality (Gray, 1970, 1981, 1987; Gray & McNaughton, 2000).

3.1 The reinforcement sensitivity theory of personality

Gray's reinforcement sensitivity theory (RST) of personality (Gray, 1970, 1981, 1987; Gray & McNaughton, 2000) links individual differences in motivational approach-avoidance systems to the individual differences in positive and negative emotionality. In contrast to Eysenck's theory (Eysenck, 1967) that views arousal as a cause of emotion, Gray's theory views emotion as a cause of arousal. The revised RST (e.g., Gray & McNaughton, 2000, McNaughton & Corr, 2004, 2008) explains individual differences in emotional reactivity in terms of underlying differences in three major neurobiological approach-avoidance systems: the behavioral approach system (BAS), the flight-fight-freeze system (FFFS), and the behavioral inhibition system (BIS). The relationship between the BAS, the FFFS, and the BIS is shown in Figure 4. The BAS is activated by appetitive signals of reward and nonpunishment (active avoidance), its activation results in approach behaviors and in the experience of positive emotions. The FFFS is activated by signals of threat and punishment, its activation results in escape and avoidance behaviors. The BIS is activated by conflicting stimuli (e.g., due to concurrent activation of the BAS and FFFS), and its activation is associated with the inhibition of ongoing behavior, an increase of attention and arousal, and with the experience of negative emotions. Individual differences in these three systems give rise to individual differences in personality traits. The BAS is thought to reflect the impulsivity personality dimension, while the defensive systems are assumed to underlie the fear (FFFS) and anxiety (BIS) dimension. In the original RST formulated by Gray (e.g., 1970, 1981, 1987), the BAS and the BIS were viewed as the main important systems underlying individual differences in emotional reactivity, in which the BIS and not the FFFS mediated responses to aversive stimuli. The revised RST (e.g., Gray & McNaughton, 2000, McNaughton & Corr, 2004, 2008) separates fear from anxiety, proposing a two-dimensional defensive system: defensive direction and defensive distance. The FFFS mediates behaviors that remove and animal from danger (defensive avoidance) and the BIS mediates behaviors that allow to approach the source of danger (defensive approach). The second dimension of the defensive system, i.e., defensive distance, determines behavioral output based on the perceived distance from the source of danger.

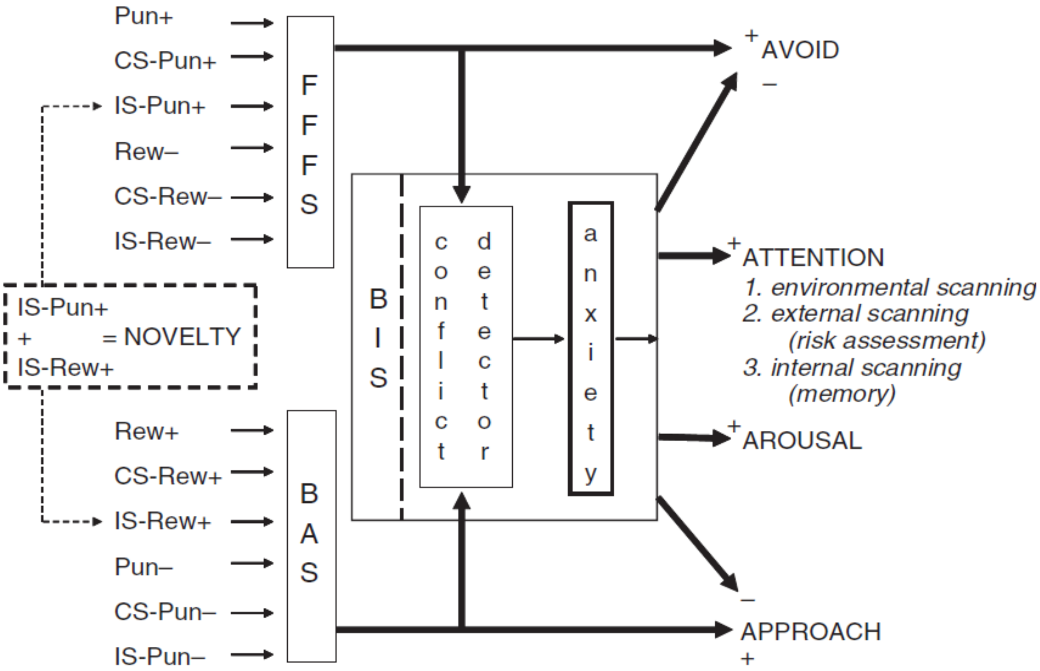


Figure 4. Relationship between the Behavioural Approach System (BAS), the Fight-Flight-Freeze System (FFFS), and the Behavioural Inhibition System (BIS). Stimuli that give input to the systems are classified in terms of the delivery (+) or omission (−) of rewards (Rew) or punishers (Pun) or conditional stimuli (CS) or innate stimuli (IS). Figure reused with permission from McNaughton and Corr (2004) Elsevier.

3.2 The role of the BAS, FFFS, and BIS in emotional attention and memory

Research is nonexistent that investigated the predictions of the RST in relation to attentional mechanisms in the visual perception of and memory for emotional events. Nevertheless, it has been shown that high-BAS participants show greater reductions in the attentional focus in response to appetitive stimuli than low-BAS participants. No effect has been observed for the BIS (Gable & Harmon-Jones, 2008). However, this study did not assess the modulatory influence of the BIS and BAS on the focus of attention associated with negative stimuli. Further, the BAS has been observed to be positively associated with memory for positive information, while the BIS is positively associated with memory for negative information (Gomez, Cooper, McOrmond, & Tatlow, 2004; Gomez & Gomez, 2002).

Viewed in the context of Gray's theory (Gray 1971, 1987; Gray & McNaughton, 2000), the trait-congruency hypothesis raises the possibility that personality traits associated with the BAS and the BIS would be useful predictors of individual differences in emotional attention and memory. Indeed, attentional biases in exogenous attention to threatening information have been found to be associated with trait anxiety (Bishop, Jenkins, & Lawrence, 2007). Regarding trait influences on emotion modulation of memory, extraversion has been found to correlate with better memory for positive information, while neuroticism has been found to correlate with increased memory for negative information (e.g., Gomez, Gomez, & Cooper, 2002; Larsen & Ketelaar, 1991; Martin, Ward, & Clark, 1983; Ruiz-Caballero & Bermúdez, 1995; Rusting; 1999; Rusting & Larsen, 1998; Young & Martin, 1981). A meta-analytic study revealed that trait anxiety is associated with a memory bias for threatening information. However, this effect was only observed for studies employing a free recall task but not for studies that utilized a recognition task or implicit memory task (Mitte, 2008). Further, heightened trait anxiety levels have been found to be associated with increased recognition of angry distractor faces in a working memory task, relative to neutral distractor faces (Denkova, Wong, Dolcos, Sung, Wang, Coupland, & Dolcos, 2010).

Individual differences in trait emotionality modulate emotional influences on attention and memory. Nevertheless, research is scarce with regard to the influence of individual differences in the RST systems on emotional attention and memory in non-clinical populations. Further, the majority of studies are behavioral studies. Therefore, it remains unclear how the observed differences in the abovementioned studies with regard to individual differences in the RST systems (BAS, FFFS, BIS) on emotional attention and memory translate into differential neurophysiological responses. Clarification of the role of the RST systems is crucial as extreme levels of fear, anxiety, and approach systems have been related to clinical disorders (e.g., Pickering, & Gray, 1999; for a review see Bijttebier et al., 2005).

4. Aims and Outline of the Thesis

The findings reviewed in this chapter suggest that the emotional effects on attention and memory occur rather automatic, at least for arousing emotional stimuli. In contrast, preliminary findings suggest that controlled encoding processes are involved in the emotional effects for low-arousing emotional stimuli. Further, how individual differences in emotional reactivity modulate (maladaptive) emotional processing remains to be clarified. The aim of the current thesis is twofold. First, a central aim of the thesis is to investigate behavioral and electrophysiological correlates of attentional mechanisms in emotional information processing and to clarify the relative contribution of emotional valence and arousal on cognition (i.e., attention and memory). Second, we examined the influence of individual differences in fear, anxiety, and approach systems on emotional information processing.

In Chapter 2 we examine the influence of individual differences in the RST systems (BAS, FFFS, BIS) on controlled emotional information processing. Next, in Chapter 3 we examine the neurophysiological correlates of exogenous attention to emotional stimuli. In Chapter 4 we investigate electrocortical correlates of attentional mechanisms underlying short-term and long-term recognition memory for affective stimuli. In Chapters 3 and 4 we further examine the contribution of individual differences in fear, anxiety, and approach systems on emotional information processing. Chapter 5 examines the functional significance of the late posterior negativity. Specifically, we investigate whether this component is linked to stimulus retrieval processes or rather to controlled stimulus evaluation or response preparation processes. Finally, Chapter 6 discusses the main findings and the implications of the research presented in this thesis.

Chapter 2

Personality, affective evaluations, and emotional memory: Comparing Eysenck's and Gray's theory in relation to emotional information processing

This chapter is based on: Sommer, K., & De Pascalis, V. (submitted). Personality, affective evaluations, and emotional memory: Comparing Eysenck's and Gray's theory in relation to emotional information processing.

Abstract

Individuals preferentially process emotional stimuli that are emotionally congruent with their current mood state and/or with their dominant personality traits. The current study compared Eysenck's and Gray's theory in understanding personality differences across emotional information processing tasks and it further examined how trait-congruency effects for affective evaluations influence trait-congruency effects in the memory performance for the affective evaluations. Participants rated either images or words with regard to valence and arousal properties and incidental memory performance (recognition or free recall) for the rated material was assessed ten minutes after the affective rating task. The results demonstrated differential trait congruency effects between stimuli (words vs. images), between valence and arousal ratings, and between different indices of memory performance. More importantly, trait-congruency effects moderated the relationship between valence ratings and memory performance for images, while arousal ratings mediated trait-congruency effects in the memory performance for words. Overall, the results across the emotional processing tasks provide evidence for trait-congruency effects with regard to Gray's theory, while little support was obtained for the involvement of Eysenck's personality dimensions. The implications regarding the relationship between personality and emotional information processing across cognitive domains are discussed.

1. Introduction

The susceptibility to experience negative and positive affect has been linked to individual differences in specific personality traits. Eysenck's biological model of personality (Eysenck, 1967) proposes two major personality dimensions, extraversion and neuroticism, and it explains differences in emotional reactivity in terms of underlying differences in cortical arousal/activation of two brain circuits. Extraversion is related to the ascending reticular activating system that controls the level of cortical arousal in response to sensory stimulation. Introverts are more arousable and generally have higher levels of cortical arousal due to their lower response thresholds of the ascending reticular activating system, while extraverts engage in arousal seeking activities to compensate for their lower levels of cortical arousal. Neuroticism is related to the limbic system that controls emotional responses and this system is more arousable in people high in neuroticism than in people who are emotionally stable, with the result that individuals high in neuroticism become more aroused and distressed in stressful or emotional situations. Although Eysenck's theory is not directly linked to positive and negative affect, a large number of studies have shown that extraversion correlates with positive affect while neuroticism correlates with negative affect (e.g., Costa & McCrae, 1980; Larsen & Ketelaar, 1991). Another major personality theory that links personality to positive and negative affect is Gray's reinforcement sensitivity theory (RST) of personality (Gray, 1970, 1981, 1987; Gray & McNaughton, 2000). The RST explains individual differences in emotional reactivity in terms of underlying differences in three major neurobiological approach-avoidance systems: the behavioral approach system (BAS), the flight-fight-freeze system (FFFS), and the behavioral inhibition system (BIS). The BAS is thought to reflect the impulsivity personality dimension, it is sensitive to appetitive signals of reward and nonpunishment (active avoidance), and its activation is associated with approach behaviors and the experience of positive emotions. The FFFS is linked to the emotion of fear, it is sensitive to signals of threat and punishment, and its activation is associated with escape and avoidance behaviors. The BIS is thought to reflect the anxiety personality dimension, it is activated by goal-conflicting stimuli (i.e. approach-avoidance conflict due to simultaneous activation of the BAS and FFFS), and its activation is associated with the inhibition of ongoing behavior, risk assessment, and the experience of negative emotions.

Individuals preferentially process emotional stimuli that are emotionally congruent with their current mood state (mood-congruency hypothesis; Bower, 1981, 1991) and/or with their dominant personality traits (trait-congruency hypothesis; Rusting, 1998). There is strong empirical support for both the mood-congruency and trait-congruency hypothesis showing that mood states and personality traits influence emotional information processing, such as perception, attention, memory, and judgments (for a review see Rusting, 1998). Consistent with the predictions of Grays's (1970, 1981, 1987) and Eysenck's theory (1967), data are showing that BAS and extraversion are associated positively with pleasant emotional information processing, while BIS and neuroticism are associated positively with unpleasant emotional information processing (e.g., Bradley & Mogg, 1994; Bradley, Mogg, Galbraith, & Perrett, 1993; De Pascalis & Speranza, 2000; Gomez, Cooper, McOrmond, & Tatlow, 2004; Gomez & Gomez, 2002; Gomez, Gomez, & Cooper, 2002; Leikas & Lindeman, 2009; Martin, Ward, & Clark, 1983; Rafienia, Azadfallah, Fathi-Ashtiani, & Rasoulzadeh-Tabatabaiei, 2008; Ruiz-Caballero & Bermúdez, 1995; Rusting; 1999; Rusting & Larsen, 1998; Tamir & Robinson, 2004; Vuoskoski & Eerola, 2011; Young & Martin, 1981; Zelenski & Larsen, 2002). Studies have further shown that (induced) mood states and personality traits interact in their influence on emotional information processing, showing that under positive mood states extraversion is associated positively with pleasant emotional information processing, whereas under negative mood states neuroticism is associated positively with unpleasant emotional information processing (e.g., Bradley & Mogg, 1994; Rafienia et al., 2008; Rusting; 1999; Tamir & Robinson, 2004; Vuoskoski & Eerola, 2011). Yet, there is some evidence indicating that when natural mood is involved instead of employing a mood induction procedure, personality traits, but not mood states, predict emotional information processing (Gomez & Gomez, 2002; Gomez et al., 2002; Rusting, 1999; Rusting & Larsen, 1998; Zelenski & Larsen, 2002). Emotional processing biases are often explained in terms of associative network theories, such as the network theory of affect (Bower, 1981, 1991; Bower & Cohen, 1982). According to this theory, emotions are represented as nodes within a cognitive network linking together emotion related cognitions and memories. The experience of an emotion results in the activation of the corresponding emotion node together with beliefs and memories of past events associated with that particular emotion. Although it was developed to account for mood effects on cognitive processes, it has been noted that the network theory of affect (e.g., Bower, 1981) can be extended to account for trait differences in emotional information processing (e.g., Clark & Teasdale, 1985). Trait differences in affect may result in different associative networks between individuals due to their differential susceptibility to specific emotions (Rusting, 1998).

Few studies have examined trait (and mood) influences on emotional information processing across a variety of cognitive processing tasks (Gomez et al., 2002, 2004; Gomez & Gomez, 2002; Leikas & Lindeman, 2009; Martin, Ward, & Clark, 1983; Rafienia et al., 2008; Rusting, 1999; Rusting & Larsen, 1998). Although these studies report stable trait-congruent effects across tasks, showing that personality and mood effects generalize across cognitive domains, it remains unclear how trait influences on emotional information processing in one cognitive domain affect trait-congruent effects in another cognitive domain. It is possible that the observed trait congruency effects in affective evaluations influenced the observed trait congruency effects in the subsequent memory tasks. Extroverts, for instance, may recall more positive words than introverts because of the associated enhanced pleasantness ratings that were completed prior to the recall task. Alternatively, the relationship between pleasantness ratings of positive words and subsequent recall performance (e.g., Bradley, Greenwald, Petry, & Lang, 1992) may be stronger for extroverts than introverts. Thus, rather than treating and examining affective evaluations and memory performance as separate, independent variables, for instance, one might gain valuable insight into underlying trait processes by examining potential mediator or moderator relationships between trait differences in affective evaluations and subsequent trait differences in memory performance for affective material. Moderating and mediating mechanisms represent trait processes that help explain how personality traits affect the outcome rather than focusing on the prediction of behavior itself (Hampson, 2012). Moderation refers to a third variable (e.g. personality trait) that affects the direction and/or strength of the relationship between a (non-trait) predictor and the outcome, while mediation refers to a third (non-trait) variable that represents the mechanism through which the predictor (e.g. personality trait) affects the outcome (Baron & Kenny, 1986). Extraversion, neuroticism, and BIS have been shown to moderate mood-congruency effects in emotional information processing (e.g., Augustine, Larsen, & Elliot, 2013; Bradley et al., 1993; Rusting, 1999; Tamir & Robinson, 2004; Vuoskoski & Eerola, 2011).

Research testing mediation is scarce and studies have generally failed to demonstrate a mediator effect for mood on trait-congruency effects in emotional information processing (Rusting, 1998; Rusting & Larsen, 1998; Zelenski & Larsen, 2002). Studies examining the relationship between personality traits and factors other than mood on emotional information processing are almost nonexistent. It has been shown that neuroticism moderates the relationship between performance on an emotional categorization task (i.e. threat identification task) and successive recall performance for the stimuli presented during the categorization task (Leikas & Lindeman, 2009) and that neuroticism moderates the relationship between implicit stress-aggression associations and physical aggression (Moeller, Robinson, & Bresin, 2010).

The majority of studies used word stimuli in the emotional processing tasks. Differences in the processing of word stimuli and picture stimuli have been observed: emotional pictures, but not words, produced interference effects in an emotional Stroop task (De Houwer & Hermans, 1994), memory performance has been found to be better for pictures compared to words (i.e. picture superiority effect; e.g., Paivio & Csapo, 1973), semantic processing is facilitated for pictures relative to words (Carr, McCauley, Sperber, & Parmelee, 1982), and emotional pictures, relative to emotional words, have been linked to increased activation of brain areas and enhanced neurophysiological responses associated with affective processing (e.g., Hinojosa, Carretié, Valcárcel, Méndez-Bértolo, & Pozo, 2009; Kensinger & Schacter, 2006). To account for the differences between pictures and words in information processing, one theory proposes a distinction between a semantic system, which contains semantic knowledge, and a lexicon, which contains linguistic knowledge (e.g., Glaser 1992; Glaser & Glaser, 1989). The semantic system is involved in the perception of images, while the lexicon controls language perception and production. According to this view, pictures have advantaged access to nodes of the semantic system, because words require additional processing before activating the semantic system. Thus, since pictures and words are differentially influenced by affective information, studies examining trait differences in emotional information processing should allow for a comparison of picture and word stimuli to gain a better understanding of personality effects across cognitive domains.

The current study compared Eysenck's and Gray's theory in understanding trait differences associated with affective ratings and subsequent memory performance for the rated affective material. Participants rated either images or words with regard to valence and arousal properties and an unexpected memory task (recognition or free recall) followed ten minutes after the affective rating task. Affective material varied in arousal level (high, low) to allow for an assessment of arousal influences on trait differences in emotional information processing. It was expected that extraversion and BAS traits are associated positively with affective ratings of positive stimuli and memory performance for positive stimuli, while it was expected that neuroticism, FFFS, and BIS are associated positively with affective ratings of negative stimuli and memory performance for negative stimuli. We further expected that affective ratings are positively related to memory performance for the rated affective material and we therefore examined the possibilities that (1) the relationship between affective ratings and memory performance is further modulated by congruent personality traits or (i.e. moderation) or that (2) the observed trait-congruency effects are the results of differences in affective ratings (i.e. mediation). Psychometric evidence, as well as theoretical grounds, indicate that the BAS is multidimensional (e.g., Carver & White, 1994; Corr, 2008; Corr & Cooper, 2016). The primary function of the BAS is to move along the temporal-spatial gradient towards the biological reinforcer and this process consists of several sub-processes (i.e., sub-goal scaffolding): (a) identification of the biological reinforcer, (b) planning behavior, and (c) implementing the plan (e.g., Corr, 2008). Therefore, the current study further investigated possible differences between BAS components with regard to trait-congruency effects in emotional information processing.

2. Method

2.1 Participants

The sample consisted of 153 participants, which were recruited from the La Sapienza University of Rome and from the general population. The participants were randomly assigned to one of the three conditions: image recognition, word recognition, and word recall condition. Fifty-four participants were assigned to the image recognition condition. Seven participants did not complete the memory task, leaving a sample size of 47 participants (24 females, 23 males), ranging in the age from 19 to 49 years (*M* = 24.68, *SD* = 5.57), for the analyses. A total of 49 participants were assigned to the word recognition condition. Two participants were excluded from the analyses because their native language was not Italian, leaving a final sample size of 47 participants (25 females, 22 males), ranging in the age from

18 to 49 years (*M* = 24.26, *SD* = 6.35), for the analyses. Fifty participants were assigned to the word recall task. One participant did not complete the memory task and another participant was excluded from the analyses due to Italian not being the native language. Thus, the final sample consisted of 48 participants (24 females, 24 males) ranging in the age from 19 to 49 years (*M* = 25.98, *SD* = 6.38). There were no age or sex differences between the conditions, all *p*s > .05. The study was approved by the local ethics committee and all participants gave written informed consent.

2.2 Materials

2.2.1 Questionnaires

Personality Questionnaires. The Reinforcement Sensitivity Theory Personality Questionnaire (RST-PQ; Corr & Cooper, 2016) is based on the revised RST (Gray & McNaughton, 2000) and it was used as a measure of BIS, FFFS, BAS (BAS-tot), and four BAS factors: Reward Interest (RI), Goal-Drive Persistence (GDP), Reward Reactivity (RR), and Impulsivity (Imp). The Eysenck Personality Questionnaire - Revised (EPQ-R; Eysenck, Eysenck, & Barrett, 1985) was used as a measure of Extraversion and Neuroticism.

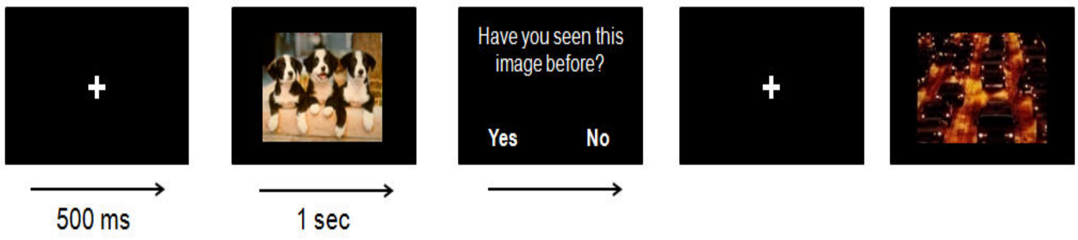
Mood States. The Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988) was used to assess positive and negative mood states. The self-report measure consists of ten positive and ten negative adjectives that describe different feelings and emotions (e.g., ‘upset’, ‘interested’). Respondents are asked to indicate how each item describes how they feel this way at the moment. Each item is rated on a 5-point scale, ranging from 1 (very slightly or not at all) to 5 (extremely).

2.2.2 Emotional information processing tasks

Affective Rating Task. Word stimuli were selected from an Italian dictionary (De Mauro, Mancini, Vedovelli, & Voghera, 1993) so that they did not differ in frequency of use and length. The images were selected from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008) and from the Geneva Affective Picture Database (GAPED; Dan-Glauser & Scherer, 2011). Two sets of words were created, with each set containing 465 words, and four sets of images were created, with each set containing 335 images. The word and image sets, respectively, did not differ with regards to valence and arousal ratings, all *p*s > .05, and there were no significant differences in frequency of use (*M* = 4.75, *SD* = 7.67) and length (4-7 characters) between the word sets, *p* > .05. The stimuli, along with the rating scales, were presented on a computer screen. Affective ratings were obtained using a 9-point Likert scale, ranging from 1 (negative valence or low arousal) to 9 (positive valence or high arousal).

Memory Tasks. Regarding the image and word recognition task, 240 stimuli of the affective rating task (48 positive/low-arousal stimuli, 48 positive/high-arousal stimuli, 48 negative/low-arousal stimuli, 48 negative/high-arousal stimuli, and 48 neutral stimuli) were presented again, together with 240 new stimuli, previously not rated during the rating task (48 positive/low-arousal stimuli, 48 positive/high-arousal stimuli, 48 negative/low-arousal stimuli, 48 negative/high-arousal stimuli, and 48 neutral stimuli). The word and image memory sets, respectively, did not differ with regards to valence and arousal ratings, all *p*s > .05. Every trial started with the presentation of a fixation cross for 500 ms. Next, an image or a word, respectively, was presented on the screen for one second. After the offset of each stimulus, the participants were asked to make yes/no recognition judgments. The time to respond was not limited. Figure 1 shows a schematic of the trial structure of the recognition tasks. With regard to the word recall task, the participants were instructed to write down as many words as they remembered from the words presented during the affective rating task. They had a maximum of 10 minutes to complete this task.

(a) Images



(b) Words

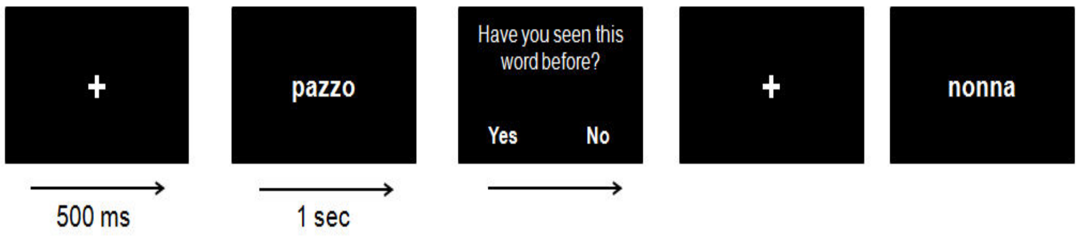


Figure 1. Schematic of the trial structure of the memory recognition task for the image recognition condition (a) and the word recognition condition (b).

2.3 Procedure

Participants were tested individually or in groups of two. Before the experiment started, the participants read and signed the informed consent and they filled in the PANAS questionnaire to assess baseline positive and negative mood states. The affective rating task was followed by the memory task 10 minutes after the rating task had finished. During those 10 minutes, the participants compiled several personality questionnaires (RST-PQ, EPQ-R), which were, if needed, completed after the memory task. The participants were not informed that their memory would be tested subsequently. After the memory task, the participants filled in again the PANAS questionnaire. At the end of the experiment, participants were thanked and debriefed.

2.4 Data Analysis

Overall Performance. Mean valence and arousal ratings were calculated for the stimuli presented in the memory recognition tasks. For the word free recall condition, mean valence and arousal ratings were calculated based on the whole sample of stimuli presented during the rating task. Valence and arousal ratings were analyzed separately using a 5 x 3 ANOVA for repeated measures with Emotion (positive/low-arousal, positive/high-arousal, negative/low-arousal, negative/high-arousal, and neutral) as within-subject factor and Condition (image recognition, word recognition, word free recall) as between subject factor. Regarding the memory recognition tasks, we analyzed the hit rate, discrimination accuracy, and false alarms (i.e. old stimulus classified as new). The hit rate refers to the proportion of correct responses and it consists of true recognitions and lucky guesses that occur from the uncertain state. The discrimination index *Pr* refers to the probability that an old item will exceed the recognition threshold for being classified as old. Higher Pr values [p(hit) - p(false alarm)] indicate enhanced discrimination between old and new items (Snodgrass & Corwin, 1988). Hit rates, Pr values, and false alarms (i.e. new stimulus classified as old) were analyzed using a 5 x 2 ANOVA for repeated measures with Emotion (positive/low-arousal, positive/high-arousal, negative/low-arousal, negative/high-arousal, and neutral) as within-subject factor and Condition (image recognition, word recognition) as between subject factor. Analyses including the factor gender revealed no gender differences. Therefore, this factor was not further considered in the analyses. Regarding the word recall condition, the number of correctly recalled words were analyzed using the same analysis, but without the between-subject factor Condition. Bonferroni corrected follow-up comparisons were conducted on significant main and interaction effects ($\alpha = 0.05$) that included the factor Emotion. Degrees of freedom were adjusted using Huynh-Feldt adjustments, in instances where the assumption of sphericity was violated.

Personality and Differential Performance. Zero-order correlations were performed to evaluate the relation of behavioral measures (hit rate, Pr value, false alarms, affective ratings) with mood (positive and negative affect) and personality measures (extraversion, neuroticism, BIS, FFFS, BAS-tot, BAS-RI, BAS-GDP, BAS-RR, BAS-Imp). To control for type 1 errors associated with multiple comparisons, the bias-corrected bootstrap method (5000 samples) was used to assess the significance of the correlations (Efron, 1982).

3. Results

3.1 Personality Measures

Descriptives of the personality measures (Extraversion, Neuroticism, BIS, FFFS, BAS-tot, BAS-RI, BAS-GDP, BAS-RR, BAS-Imp) across conditions are presented in Table 1. Results of a one-way ANOVA indicated that Extraversion scores differed between conditions, $F(2,136) = 3.98$, $p = .021$.[1] Post-hoc comparisons showed that extraversion scores were higher in the word recognition condition relative to the free recall condition ($p = .017$). No other differences were observed between conditions, all *p*s > .05.

3.2 Personality and Mood Measures

Positive and negative mood states did not differ between the experimental conditions, all *F*s < 1. Zero-order correlations were performed to examine the relationship between personality traits and baseline positive and negative mood states. The correlation coefficients demonstrate the expected relationship between extraversion and BAS traits with positive mood states (range of significant *r* coefficients: 0.31, 0.58) and between neuroticism and BIS with negative mood states (range of significant *r* coefficients: 0.29, 0.56).

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[1] Due to missing responses, extraversion and neuroticism scores could not be calculated for three participants in the image recognition condition.

Table 1. *Descriptives (means and standard deviations) of the personality measures for each experimental condition.*

Measure	Image Recognition Condition	Word Recognition Condition	Word Recall Condition
Extraversion	13.32 (4.74)	14.79 (4.59)	12.08 (4.69)
Neuroticism	13.36 (4.83)	12.15 (5.16)	13.48 (4.92)
BIS	54.02 (13.46)	50.36 (13.03)	53.44 (12.34)
FFFS	23.13 (6.02)	22.21 (5.81)	21.90 (5.78)
BAS-tot	85.32 (13.04)	84.11 (12.39)	81.23 (11.48)
BAS-RI	19.00 (3.31)	18.79 (3.58)	17.62 (4.00)
BAS-RR	28.00 (4.99)	28.00 (4.44)	27.25 (3.97)
BAS-GDP	19.28 (4.37)	19.11 (4.27)	18.48 (4.62)
BAS-Imp	19.04 (4.43)	18.21 (4.09)	17.88 (3.78)

3.3 Affective Ratings

3.3.1 Overall performance

Valence ratings. The ANOVA performed on the valence scores yielded the expected main effect for Emotion, $F(1.62,225.31) = 961.41$, $p < .0001$, $\eta^2_p = .87$. As can be seen in Table 2, positive high and low-arousal stimuli were rated as more pleasant than neutral and negative stimuli and negative low and high-arousal stimuli were rated as more unpleasant than neutral stimuli, all *p*s < .0001. Negative/high-arousal stimuli were rated as more unpleasant than negative/low-arousal stimuli, $F(1,139) = 602.03$, $p < .0001$, $\eta^2_p = .81$, and positive/high-arousal stimuli were rated as more pleasant than positive/low-arousal stimuli, $F(1,139) = 15.24$, $p < .0001$, $\eta^2_p = .10$. Further, words in the recognition condition and recall condition were rated as more pleasant than images, main effect of Condition, $F(2,139)$ 14.85, $p < .0001$, $\eta^2_p = .18$. Valence ratings differed between Conditions, Emotion x Condition, $F(3.24,225.31) = 8.65$, $p < .0001$, $\eta^2_p = .11$. Post-hoc comparisons indicated that neutral stimuli were rated as more pleasant in the word recognition condition compared to the image recognition condition ($p < .0001$) and the word recall condition ($p = .007$). Further, negative/low-arousal stimuli were rated as more unpleasant in the image recognition condition than in the word recognition condition (*p* <. 0001), and positive/low-arousal stimuli were rated as more pleasant in the word recognition condition compared to the word recall condition (*p* = .009). No other effects were observed, all *p*s > .05.

Table 2. *Mean valence and arousal ratings across affective categories as a function of experimental condition.*

	Neutral	Neg-High	Neg-Low	Pos-High	Pos-Low
(1) Image Recognition Condition					
Valence Rating	4.84 (0.36)	2.69 (0.89)	3.39 (0.80)	6.42 (0.73)	6.76 (0.74)
Arousal Rating	3.38 (1.01)	6.61 (1.11)	5.31 (1.09)	4.63 (1.16)	3.24 (1.25)
(2) Word Recognition Condition					
Valence Rating	5.54 (0.72)	2.96 (0.63)	4.19 (0.53)	6.39 (0.50)	6.80 (0.79)
Arousal Rating	3.87 (1.27)	6.08 (1.64)	4.60 (1.38)	4.54 (1.38)	3.54 (1.28)
(3) Word Recall Condition					
Valence Rating	5.22 (0.35)	3.14 (0.66)	4.16 (0.48)	6.61 (0.62)	6.36 (0.62)
Arousal Rating	4.17 (1.12)	6.16 (1.24)	4.71 (1.05)	4.73 (1.12)	3.85 (1.03)

Note: Standard deviations are reported in parentheses. Neg-High = negative/high-arousal images, Neg-Low = negative/low-arousal images, Pos-High = positive/high-arousal images, Pos-Low = positive/low-arousal images.

Arousal ratings. The ANOVA performed on the arousal scores demonstrated a main effect for Emotion, *F*(2.26,313.78) = 298.76, $p < .0001$, $\eta^2_p = .68$, but no main affect for Condition, *F*(2,139) < 1, $p > .05$. In Table 2 it can be seen that emotional stimuli were rated as more arousing than neutral stimuli, all *p*s <.0001, except for positive/low-arousal stimuli which were rated as less arousing than neutral stimuli, *F*(1,139) = 11.38, $p = .001$, $\eta^2_p = .09$. Negative/high-arousal stimuli were rated as more arousing than negative/low-arousal stimuli, *F*(1,139) = 496.50, $p < .0001$, $\eta^2_p = .78$, and positive/high-arousal stimuli were rated as more arousing than positive/low-arousal stimuli, *F*(1,139) = 381.89, $p < .0001$, $\eta^2_p = .73$. Low and high-arousal negative stimuli were rated as more arousing than low and high-arousal positive stimuli, respectively, all *p*s < .0001. Arousal ratings differed between Conditions, Emotion x Condition, *F*(4.52,313.78) = 9.42, p < .0001, η^2_p = .12. Post-hoc comparisons indicated that arousal ratings for negative/low-arousal stimuli were greater in the image recognition condition than in the word recognition condition (*p* = .013). No other effects were observed, all *p*s > .05.

3.3.2 Personality and differential performance

The zero-order correlation coefficients for the valence and arousal ratings, along with their 95% associated bootstrapped confidence intervals, are reported in Table 3 and Table 4, respectively, for each experimental condition.

Valence ratings. Correlation coefficients demonstrated that positive mood states, but not negative mood states, correlated negatively with valence ratings for high and low-arousal negative stimuli in the image recognition condition and in the word recall condition, while positive mood was positively related to valence ratings for high and low-arousal positive stimuli in the word recall condition. No other mood effects were observed, all *p*s > .05. In the image recognition condition, BAS traits (BAS-tot, BAS-RR, and BAS-GDP) correlated negatively with valence ratings for high and low-arousal negative images and positively with valence ratings for high-arousal positive images. In the word recall condition, BAS traits (especially BAS-RR) correlated negatively with valence ratings for high-arousal negative words and positively with valence ratings for high and low-arousal positive words. Fisher r-to-z transformations revealed no significant differences between the various BAS traits, all *p*s > .05. The FFFS correlated negatively with valence ratings for negative/low-arousal images. Extraversion correlated positively with valence ratings for low-arousal positive words in the word recognition condition. No effects were obtained for the BIS and neuroticism, all *p*s > .05.

Arousal ratings. Correlation coefficients indicated that the influence of mood states and personality traits was restricted to low and high-arousal negative words and images. Positive mood, but not negative mood, correlated positively with the arousal ratings of low and high-arousal stimuli in the image recognition condition. No mood effects were observed for the word recognition condition and for the word recall condition. In the image and word recognition condition, BAS traits were positively associated with arousal ratings of negative high and low-arousal stimuli. No significant differences emerged between the various BAS traits, all *p*s >

Table 3. Zero-*order correlations, along with their 95% associated bootstrapped confidence intervals, of the valence ratings across affective categories with the personality measures.*

Measure	Neutral	Neg-High	Neg-Low	Pos-High	Pos-Low
(1) Image Recognition Condition					
Positive mood	-0.24 (-0.49, 0.06)	-0.46 (-0.62, -0.27)†	-0.52 (-0.69, -0.30)†	0.24 (-0.05, 0.51)	0.26 (-0.03, 0.52)
Negative mood	0.04 (-0.34, 0.39)	0.04 (-0.34, 0.40)	0.03 (-0.35, 0.38)	-0.14 (-0.44, 0.16)	-0.13 (-0.46, 0.19)
Extraversion	-0.12 (-0.39, 0.21)	-0.02 (-0.26, 0.23)	-0.06 (-0.35, 0.24)	0.09 (-0.20, 0.36)	0.03 (-0.31, 0.31)
Neuroticism	-0.06 (-0.30, 0.19)	0.14 (-0.14, 0.38)	0.12 (-0.21, 0.40)	-0.32 (-0.60, 0.02)*	-0.26 (-0.55, 0.06)
BIS	-0.01 (-0.24, 0.21)	-0.06 (-0.34, 0.23)	-0.01 (-0.31, 0.29)	-0.14 (-0.42, 0.19)	0.05 (-0.25, 0.33)
FFFS	-0.26 (-0.54, 0.05)	-0.28 (-0.52, 0.02)	-0.32 (-0.57, -0.04)*	-0.07 (-0.27, 0.41)	0.16 (-0.13, 0.43)
BAS-tot	-0.22 (-0.51, 0.15)	-0.33 (-0.57, -0.09)*	-0.37 (-0.63, -0.08)*	0.42 (0.08, 0.68)†	0.23 (-0.05, 0.49)
BAS-RI	-0.02 (-0.32, 0.32)	-0.19 (-0.43, 0.06)	-0.19 (-0.46, 0.12)	0.36 (0.05, 0.61)*	0.22 (-0.08, 0.50)
BAS-RR	-0.24 (-0.48, 0.08)	-0.30 (-0.51, -0.10)*	-0.35 (-0.56, -0.13)*	0.33 (0.06, 0.59)*	0.18 (-0.08, 0.43)
BAS-GDP	-0.22 (-0.50, 0.10)	-0.33 (-0.57, -0.07)*	-0.31 (-0.56, -0.01)*	0.30 (-0.02, 0.47)*	0.15 (-0.13, 0.42)
BAS-Imp	-0.14 (-0.48, 0.25)	-0.17 (-0.44, 0.11)	-0.24 (-0.53, 0.08)	0.29 (-0.03, 0.57)*	0.17 (-0.09, 0.42)
(2) Word Recognition Condition					
Positive mood	0.22 (-0.10, 0.54)	0.04 (-0.27, 0.35)	0.01 (-0.28, 0.31)	0.30 (-0.03, 0.58)	0.27 (-0.03, 0.52)
Negative mood	-0.29 (-0.56, 0.00)	0.09 (-0.12, 0.32)	-0.16 (-0.47, 0.12)	-0.11 (-0.38, 0.28)	-0.12 (-0.38, 0.19)
Extraversion	0.24 (-0.01, 0.47)	-0.04 (-0.32, 0.24)	0.03 (-0.27, 0.33)	0.23 (-0.02, 0.47)	0.32 (0.05, 0.56)*
Neuroticism	0.01 (-0.36, 0.38)	-0.14 (-0.41, 0.13)	-0.12 (-0.43, 0.23)	0.21 (-0.16, 0.55)	0.08 (-0.25, 0.37)
BIS	-0.09 (-0.48, 0.34)	-0.05 (-0.31, 0.19)	-0.23 (-0.60, 0.19)	0.07 (-0.32, 0.47)	0.06 (-0.25, 0.36)
FFFS	-0.06 (-0.43, 0.37)	-0.25 (-0.50, -0.01)	-0.31 (-0.61, 0.05)	0.03 (-0.33, 0.43)	0.08 (-0.22, 0.38)
BAS-tot	0.14 (-0.12, 0.47)	-0.06 (-0.33, 0.25)	-0.19 (-0.45, 0.11)	0.25 (0.01, 0.48)	0.25 (-0.05, 0.50)
BAS-RI	0.12 (-0.14, 0.39)	-0.04 (-0.36, 0.28)	-0.08 (-0.38, 0.20)	0.17 (-0.08, 0.42)	0.24 (-0.04, 0.50)
BAS-RR	0.02 (-0.31, 0.47)	-0.02 (-0.30, 0.27)	-0.27 (-0.54, 0.07)	0.16 (-0.16, 0.47)	0.12 (-0.20, 0.43)
BAS-GDP	0.16 (-0.04, 0.38)	-0.19 (-0.44, 0.11)	-0.17 (-0.45, 0.09)	0.20 (-0.06, 0.44)	0.18 (-0.10, 0.44)
BAS-Imp	0.14 (-0.16, 0.45)	0.06 (-0.21, 0.36)	-0.03 (-0.31, 0.28)	0.22 (-0.06, 0.48)	0.22 (-0.05, 0.47)
(3) Word Free Recall Condition					
Positive mood	0.12 (-0.12, 0.33)	-0.48 (-0.71, -0.18)†	-0.33 (-0.53, -0.11)*	0.41 (0.13, 0.64)†	0.40 (0.15, 0.62)†
Negative mood	0.06 (-0.17, 0.34)	0.22 (-0.19, 0.54)	-0.07 (-0.35, 0.24)	-0.19 (-0.39, 0.07)	0.03 (-0.18, 0.29)
Extraversion	0.19 (-0.10, 0.44)	-0.16 (-0.43, 0.10)	-0.04 (-0.29, 0.20)	0.21 (-0.02, 0.42)	0.18 (-0.06, 0.39)
Neuroticism	0.07 (-0.18, 0.28)	0.20 (-0.12, 0.47)	0.03 (-0.29, 0.32)	0.01 (-0.27, 0.25)	0.04 (-0.21, 0.29)
BIS	-0.03 (0.22, 0.19)	0.12 (-0.25, 0.44)	-0.05 (-0.38, 0.27)	0.02 (-0.25, 0.32)	0.06 (-0.20, 0.34)
FFFS	0.00 (-0.29, 0.31)	-0.23 (-0.49, 0.05)	-0.07 (-0.33, 0.20)	0.14 (-0.16, 0.42)	0.06 (-0.21, 0.32)
BAS-tot	0.17 (-0.09, 0.40)	-0.22 (-0.48, 0.05)	0.01 (-0.20, 0.20)	0.32 (0.08, 0.52)*	0.22 (-0.01, 0.43)
BAS-RI	0.04 (-0.26, 0.34)	-0.08 (-0.35, 0.19)	0.00 (-0.24, 0.25)	0.04 (-0.24, 0.29)	0.02 (-0.28, 0.30)
BAS-RR	0.25 (-0-06, 0.51)	-0.35 (-0.59, -0.08)*	-0.13 (-0.33, 0.05)	0.48 (0.24, 0.66)†	0.39 (0.17, 0.58)•
BAS-GDP	0.04 (-0.22, 0.31)	-0.21 (-0.47, 0.12)	-0.02 (-0.25, 0.22)	0.30 (0.05, 0.51)*	0.15 (-0.10, 0.38)
BAS-Imp	0.16 (-0.17, 0.43)	0.04 (-0.25, 0.33)	0.19 (-0.12, 0.45)	0.05 (-0.21, 0.32)	0.05 (-0.23, 0.33)

Note: * p < 0.05, • p < 0.01, † p < 0.005.

Table 4. Zero-*order correlations, along with their 95% associated bootstrapped confidence intervals, of the arousal ratings across affective categories with the personality measures.*

Measure	Neutral	Neg-High	Neg-Low	Pos-High	Pos-Low
(1) Image Recognition Condition					
Positive mood	-0.01 (-0.24, 0.22)	0.46 (0.29, 0.62)†	0.37 (0.18, 0.58)•	0.19 (-0.15, 0.47)	0.05 (-0.27, 0.33)
Negative mood	0.05 (-0.20, 0.28)	0.02 (-0.38, 0.43)	0.13 (-0.26, 0.49)	0.17 (-0.17, 0.45)	0.20 (-0.06, 0.43)
Extraversion	0.03 (-0.27, 0.32)	0.27 (-0.02, 0.54)	0.26 (-0.01, 0.51)	0.24 (-0.10, 0.52)	0.16 (-0.14, 0.46)
Neuroticism	0.15 (-0.17, 0.46)	-0.09 (-0.31, 0.14)	-0.05 (-0.34, 0.28)	-0.04 (-0.37, 0.34)	-0.03 (-0.30, 0.26)
BIS	0.12 (-0.18, 0.40)	0.04 (-0.24, 0.29)	-0.01 (-0.34, 0.32)	-0.16 (-0.47, 0.20)	-0.14 (-0.39, 0.14)
FFFS	-0.15 (-0.44, 0.14)	0.17 (-0.11, 0.43)	0.10 (-0.16, 0.38)	-0.28 (-0.54, 0.00)	-0.23 (-0.48, 0.02)
BAS-tot	-0.15 (-0.40, 0.13)	0.43 (0.23, 0.62)†	0.27 (-0.03, 0.50)	0.00 (-0.27, 0.26)	-0.11 (-0.35, 0.14)
BAS-RI	-0.13 (-0.40, 0.17)	0.37 (0.16, 0.57)•	0.30 (0.04, 0.52)*	0.20 (-0.16, 0.52)	0.02 (-0.26, 0.29)
BAS-RR	-0.13 (-0.38, 0.14)	0.31 (0.04, 0.57)*	0.16 (-0.09, 0.44)	-0.12 (-0.36, 0.13)	-0.20 (-0.42, 0.01)
BAS-GDP	-0.24 (-0.48, 0.04)	0.38 (0.15, 0.58)•	0.24 (-0.01, 0.45)	0.01 (-0.22, 0.25)	0.04 (-0.22, 0.28)
BAS-Imp	0.04 (-0.25, 0.33)	0.27 (0.04, 0.47)	0.15 (-0.14, 0.44)	-0.02 (-0.30, 0.28)	-0.14 (-0.39, 0.16)
(2) Word Recognition Condition					
Positive mood	0.17 (-0.14, 0.43)	0.28 (0.00, 0.54)	0.22 (-0.07, 0.48)	0.19 (-0.11, 0.45)	0.02 (-0.30, 0.29)
Negative mood	0.12 (-0.13, 0.42)	0.11 (-0.08, 0.30)	0.08 (-0.15, 0.33)	0.17 (-0.07, 0.49)	0.21 (-0.07, 0.59)
Extraversion	-0.03 (-0.34, 0.30)	0.19 (-0.14, 0.52)	0.10 (-0.23, 0.42)	-0.10 (-0.38, 0.21)	-0.23 (-0.48, 0.06)
Neuroticism	0.08 (-0.36, 0.43)	0.19 (-0.16, 0.51)	0.16 (-0.21, 0.47)	0.12 (-0.27, 0.45)	0.12 (-0.28, 0.45)
BIS	0.12 (-0.31, 0.44)	0.14 (-0.11, 0.34)	0.15 (-0.18, 0.42)	0.27 (-0.05, 0.51)	0.25 (-0.15, 0.54)
FFFS	0.19 (-0.20, 0.51)	0.28 (0.04, 0.47)	0.26 (-0.04, 0.50)	0.19 (-0.12, 0.45)	0.18 (-0.20, 0.50)
BAS-tot	0.12 (-0.13, 0.35)	0.33 (0.09, 0.55)*	0.25 (-0.01, 0.48)	0.19 (-0.03, 0.40)	0.03 (-0.27, 0.30)
BAS-RI	0.09 (-0.16, 0.34)	0.27 (0.00, 0.52)	0.18 (-0.08, 0.44)	0.05 (-0.20, 0.30)	-0.06 (-0.33, 0.22)
BAS-RR	0.17 (-0.13, 0.42)	0.30 (0.11, 0.49)*	0.30 (0.06, 0.50)*	0.27 (-0.04, 0.47)	0.18 (-0.15, 0.45)
BAS-GDP	-0.03 (-0.28, 0.29)	0.10 (-0.19, 0.40)	0.03 (-0.27, 0.34)	0.10 (-0.17, 0.39)	-0.00 (-0.32, 0.31)
BAS-Imp	0.12 (-0.17, 0.37)	0.32 (0.10, 0.55)*	0.23 (-0.04, 0.47)	0.13 (-0.12, 0.37)	-0.06 (-0.36, 0.22)
(3) Word Free Recall Condition					
Positive mood	-0.04 (-0.32, 0.25)	0.17 (-0.09, 0.40)	-0.05 (-0.30, 0.19)	0.01 (-0.27, 0.27)	-0.12 (-0.38, 0.14)
Negative mood	0.14 (-0.05, 0.32)	0.08 (-0.14, 0.30)	0.18 (-0.03, 0.35)	0.02 (-0.23, 0.21)	-0.03 (-0.25, 0.17)
Extraversion	0.02 (-0.26, 0.31)	-0.11 (-0.38, 0.23)	-0.04 (-0.32, 0.26)	0.04 (-0.28, 0.35)	0.07 (-0.22, 0.36)
Neuroticism	-0.03 (-0.34, 0.30)	0.11 (-0.13, 0.36)	0.09 (-0.18, 0.39)	-0.17 (-0.43, 0.12)	-0.20 (-0.49, 0.11)
BIS	0.06 (-0.26, 0.39)	0.19 (-0.13, 0.48)	0.17 (-0.13, 0.49)	-0.12 (-0.40, 0.20)	-0.20 (-0.49, 0.12)
FFFS	0.04 (-0.28, 0.33)	0.31 (0.01, 0.54)*	0.11 (-0.22, 0.38)	-0.03 (-0.37, 0.28)	-0.10 (-0.43, 0.22)
BAS-tot	-0.19 (-0.39, 0.02)	-0.08 (-0.30, 0.13)	-0.22 (-0.41, -0.01)	-0.09 (-0.30, 0.15)	-0.08 (-0.32, 0.15)
BAS-RI	-0.12 (-0.35, 0.12)	-0.18 (-0.38, 0.01)	-0.19 (-0.41, 0.03)	-0.10 (-0.32, 0.13)	-0.03 (-0.25, 0.19)
BAS-RR	-0.08 (-0.31, 0.14)	0.16 (-0.08, 0.35)	-0.02 (-0.28, 0.21)	-0.02 (-0.26, 0.22)	-0.11 (-0.36, 0.14)
BAS-GDP	-0.19 (-0.42, 0.04)	-0.18 (-0.40, 0.07)	-0.28 (-0.46, -0.09)	-0.11 (-0.38, 0.15)	-0.08 (-0.38, 0.21)
BAS-Imp	-0.15 (-0.43, 0.13)	0.01 (-0.30, 0.30)	-0.10 (-0.36, 0.16)	0.00 (-0.29, 0.31)	-0.01 (-0.30, 0.29)

Note: * $p < 0.05$, • $p < 0.01$, † $p < 0.005$.

.05.The FFFS correlated positively with the arousal ratings of negative/high-arousal words in the word recall condition. In contrast to expectations, no significant effects were observed for BIS, neuroticism, and extraversion, all *p*s > .05.

3.4 Memory Tasks

Descriptives (means and standard deviations) of the behavioral performance data across affective categories are presented in Table 5. The results are reported separately for each experimental condition.

Table 5. *Recognition and recall performance descriptives across affective categories as a function of experimental condition.*

Variable	Neutral	Neg-High	Neg-Low	Pos-High	Pos-Low
(1) Image Recognition Condition					
Hit	0.91 (0.06)	0.92 (0.05)	0.88 (0.07)	0.91 (0.07)	0.87 (0.08)
FA	0.07 (0.05)	0.10 (0.08)	0.12 (0.07)	0.07 (0.07)	0.07 (0.05)
Pr	0.84 (0.08)	0.82 (0.11)	0.76 (0.11)	0.84 (0.10)	0.80 (0.09)
(2) Word Recognition Condition					
Hit	0.78 (0.15)	0.81 (0.10)	0.80 (0.12)	0.79 (0.14)	0.78 (0.13)
FA	0.13 (0.10)	0.02 (0.01)	0.13 (0.11)	0.18 (0.13)	0.16 (0.12)
Pr	0.65 (0.18)	0.79 (0.10)	0.67 (0.17)	0.61 (0.16)	0.62 (0.16)
(3) Word Recall Condition					
correctly recalled	5.65 (4.79)	7.63 (4.75)	6.33 (4.25)	8.13 (5.58)	8.54 (5.08)

Note: Standard deviations are reported in parentheses. Neg-High = negative/high-arousal images, Neg-Low = negative/low-arousal images, Pos-High = positive/high-arousal images, Pos-Low = positive/low-arousal images.

3.4.1 Image Recognition and Word Recognition

3.4.1.1 Hit rates

Overall performance. Regarding the proportions of correct responses (i.e. hits), the ANOVA demonstrated the expected main effect for Condition, $F(1,92) = 32.64$, $p < .0001$, $\eta^2_p = .26$, reflecting better recognition performance for images than for words. The analysis further yielded a main effect for Emotion, $F(4,368) = 5.89$, p

$< .0001$, $\eta^2_p = .06$, but the effect of emotional content on recognition performance varied across conditions, Condition x Emotion: $F(4,368) = 2.58$, $p = .037$, $\eta^2_p = .03$. Separate ANOVAs performed on the image and word recognition data indicated an influence of affective content on recognition performance for images, main effect for Emotion: $F(4,184) = 5.89$, $p < .0001$, $\eta^2_p = .17$, but not for words, main effect for Emotion: $F(4,184) = 1.22$, $p > .05$. Post-hoc comparisons showed that recognition performance was impaired for negative and positive/low arousal images relative to neutral images (negative/low-arousal images: $F(1,46) = 8.29$, $p = .006$, $\eta^2_p = .15$; positive/low-arousal image: $F(1,46) = 23.33$, $p < .0001$, $\eta^2_p = .34$), while hit rates did not differ between neutral and high-arousal emotional images, all *F*s < 1. Negative/high-arousal images were recognized better than negative/low-arousal images, $F(1,46) = 16.14$, $p < .0001$, $\eta^2_p = .26$, and positive/high-arousal images were recognized better than positive/low-arousal images, $F(1,46) = 18.74$, $p < .0001$, $\eta^2_p = .29$. No differences in recognition performance were observed between high-arousal emotional images, $F < 1$, and between low-arousal emotional images, $F(4,184) = 1.61$, $p > .05$.

Personality and differential performance. The correlation coefficients, along with their 95% associated bootstrapped confidence intervals, are reported in Table 6. Positive and negative mood states did not correlate with hit rates across affective categories and experimental conditions, all *p*s > .05. With regard to the image recognition condition, BAS-GDP correlated negatively with the hit rates associated with negative/high-arousal images and low and high-arousal positive images. The BIS correlated positively with the memory performance for neutral images, while the FFFS was associated with impaired memory performance for negative/low-arousal images and low and high-arousal positive images. Regarding the word recognition condition, correlation coefficients indicate that BAS-tot and BAS-RR correlated negatively with the hits rates for low and high-arousal negative (and neutral) words, while no significant correlations emerged for low and high-arousal positive words. BAS-Imp correlated negatively with hit rates across affective categories. No significant differences emerged between BAS-tot, BAS-RR, and BAS-IMP and recognition performance across affective categories, all *p*s > .05. In contrast to expectations, no other personality effects were observed, all *p*s > .05.

Table 6. *Zero-order correlations, along with their 95% associated bootstrapped confidence intervals, between personality measures and mood states with hit rates across affective categories.*

Measure	Neutral	Neg-High	Neg-Low	Pos-High	Pos-Low
(1) Image Recognition Condition					
Pos mood	0.21 (-0.08, 0.45)	-0.02 (-0.34, 0.26)	0.05 (-0.27, 0.34)	-0.01 (-0.29, 0.31)	0.08 (-0.20, 0.39)
Neg mood	0.12 (-0.14, 0.31)	-0.09 (-0.38, 0.23)	0.01 (-0.34, 0.31)	0.22 (-0.04, 0.42)	0.10 (-0.13, 0.33)
Extraversion	0.09 (-0.26, 0.41)	0.30 (-0.06, 0.58)	0.10 (-0.23, 0.39)	0.22 (-0.12, 0.55)	0.14 (-0.16, 0.45)
Neuroticism	0.22 (-0.10, 0.49)	0.15 (-0.18, 0.44)	0.07 (-0.23, 0.37)	0.16 (-0.17, 0.52)	0.17 (-0.16, 0.48)
BIS	0.38 (0.18, 0.56)•	0.13 (-0.09, 0.34)	-0.05 (-0.33, 0.26)	0.13 (-0.12, 0.40)	0.16 (-0.10, 0.41)
FFFS	-0.08 (-0.31, 0.16)	-0.24 (-0.47, 0.03)	-0.31 (-0.56, -0.01)*	-0.40 (-0.59, -0.18)†	-0.30 (-0.54, -0.02)*
BAS-tot	0.09 (-0.27, 0.38)	-0.12 (-0.47, 0.03)	-0.10 (-0.39, 0.17)	-0.19 (-0.51, 0.17)	-0.19 (-0.52, 0.17)
BAS-RI	0.08 (-0.34, 0.12)	0.02 (-0.35, 0.31)	0.09 (-0.23, 0.35)	-0.03 (-0.34, 0.29)	-0.05 (-0.41, 0.31)
BAS-RR	0.17 (-0.14, 0.45)	-0.08 (-0.36, 0.17)	-0.10 (-0.37, 0.18)	-0.13 (-0.44, 0.21)	-0.05 (-0.34, 0.26)
BAS-GDP	-0.14 (-0.45, 0.13)	-0.30 (-0.54, -0.07)*	-0.16 (-0.39, 0.08)	-0.47 (-0.69, -0.21)†	-0.46 (-0.67, -0.18)†
BAS-Imp	0.14 (-0.34, 0.12)	0.03 (-0.23, 0.28)	-0.10 (-0.39, 0.16)	0.07 (-0.23, 0.38)	-0.03 (-0.32, 0.28)
(2) Word Recognition Condition					
Pos mood	-0.12 (-0.37, 0.16)	-0.21 (-0.45, 0.05)	-0.14 (-0.43, 0.17)	-0.10 (-0.36, 0.16)	-0.19 (-0.48, 0.09)
Neg mood	-0.07 (-0.34, 0.12)	-0.04 (-0.40, 0.24)	-0.02 (-0.35, 0.21)	-0.08 (-0.38, 0.15)	0.03 (-0.32, 0.25)
Extraversion	-0.14 (-0.37, 0.11)	-0.11 (-0.39, 0.20)	-0.07 (-0.36, 0.24)	0.05 (-0.28, 0.36)	-0.14 (-0.41, 0.16)
Neuroticism	-0.08 (-0.34, 0.20)	-0.22 (-0.51, 0.10)	-0.08 (-0.44, 0.27)	-0.24 (-0.54, 0.09)	-0.15 (-0.46, 0.17)
BIS	-0.03 (-0.31, 0.26)	-0.18 (-0.47, 0.15)	-0.03 (-0.37, 0.33)	-0.20 (-0.52, 0.19)	0.01 (-0.33, 0.34)
FFFS	-0.05 (-0.34, 0.25)	-0.20 (-0.47, 0.14)	-0.12 (-0.43, 0.22)	-0.13 (-0.49, 0.26)	-0.04 (-0.39, 0.33)
BAS-tot	-0.32 (-0.56, -0.06)*	-0.36 (-0.62, -0.03)*	-0.34 (-0.54, -0.10)*	-0.13 (-0.44, 0.19)	-0.25 (-0.58, 0.09)
BAS-RI	-0.27 (-0.51, -0.02)	-0.20 (-0.48, 0.11)	-0.21 (-0.45, 0.05)	-0.06 (-0.34, 0.23)	-0.25 (-0.50, 0.04)
BAS-RR	-0.24 (-0.48, 0.05)	-0.32 (-0.57, -0.02)*	-0.30 (-0.53, -0.04)*	-0.15 (-0.46, 0.19)	-0.14 (-0.49, 0.23)
BAS-GDP	-0.10 (-0.38, 0.20)	-0.11 (-0.40, 0.23)	-0.13 (-0.40, 0.16)	0.11 (-0.23, 0.42)	0.05 (-0.30, 0.37)
BAS-Imp	-0.37 (-0.60, -0.12)•	-0.46 (-0.69, 0.17)†	-0.37 (-0.58, -0.14)*	-0.29 (-0.54, -0.02)*	-0.45 (-0.69, -0.19)†

Note: * $p < 0.05$, • $p < 0.01$, † $p < 0.005$. Pos mood: positive mood, Neg mood: negative mood.

3.4.1.2 False alarms

Overall performance. False alarms (i.e. classifying new stimuli as old) were higher for words than for images, main effect for Condition: $F(1,92) = 5.99$, $p = .016$, $\eta^2_p = .06$. The ANOVA further demonstrated a significant main effect for Emotion, $F(4,368) = 29.42$, $p < .0001$, $\eta^2_p = .24$, but the effect of emotional content on false alarms differed between conditions, Condition x Emotion: $F(4,368) = 58.36$, $p < .0001$, $\eta^2_p = .39$. Follow-up analyses indicated that false alarms were higher for low and high-arousal negative images, relative to neutral images, all *p*s < .0001, while the false alarms associated with neutral images were similar to those of low and high-arousal positive images, all Fs < 1. Further, false alarms were higher for negative low-arousal images than negative/high-arousal images, $F(1,46) = 8.50$, $p = .005$, $\eta^2_p = .16$, while false alarms did not differ between low and high-arousal positive images, $F < 1$. Low and high-arousal negative images were associated with higher false alarms relative to low and high-arousal positive images, respectively, all ps < .0001. Regarding the words, follow-up analyses showed that false alarms were lower for negative/high-arousal words relative to neutral words, $F(1,46) = 63.44$, $p < .0001$, $\eta^2_p = .58$, while false alarms were enhanced for positive low and high-arousal words relative to neutral words, all ps < .005. False alarm rates did not differ between neutral and negative/low-arousal words, $F < 1$. Negative low-arousal words were associated with higher false alarm rates than negative/high-arousal words, $F(1,46) = 8.50$, $p = .005$, $\eta^2_p = .16$, whereas the false alarms did not differ between low and high-arousal positive words, all $p > .05$. Low and high-arousal positive words were associated with higher false alarms relative to low and high-arousal negative words, respectively, all ps < .005.

Personality and differential performance. Zero-order correlations indicated no significant correlations between mood states and false alarms across conditions, all ps > .05 (range of r coefficients in the image recognition condition*:* -0.18, 0.08; range of r coefficients in the word recognition condition*:* -0.01, 0.21). Regarding the personality effects, a negative correlation between BIS and false alarms for positive/high-arousal images ($r = -.28$, $p = .05$, CI 95% = -0.50,- 0.08). In the word recognition condition, extraversion correlated positively with false alarms for neutral words ($r = .35$, $p = .02$, CI 95% = 0.13, 0.55), and false alarms for negative/low-arousal words correlated positively with extraversion ($r = .33$, $p = .02$, CI 95% = 0.08, 0.53) and BAS-RR ($r = .37$, $p = .01$, CI 95% = 0.15, 0.57). The correlation coefficients did not differ between BAS-RR and extraversion, $p > .05$. No other personality effects were observed, all ps > .05 (range of r coefficients in the image recognition condition*:* -0.26, 0.28; range of r coefficients in the word recognition condition*:* -0.19, 0.26).

3.4.1.3 Pr discrimination index

Overall performance. Discrimination accuracy was higher for images than for words, main effect for Condition: $F(1,92) = 38.14$, $p < .0001$, $\eta^2_p = .29$. The ANOVA further demonstrated a significant main effect for Emotion, $F(4,368) =$

29.08, $p < .0001$, $\eta^2_p = .21$, but the effect of emotional content on discrimination accuracy differed between conditions, Condition x Emotion: $F(4,368) = 26.53$, $p < .0001$, $\eta^2_p = .22$. Regarding the images, emotional images low in arousal were associated with reduced discrimination accuracy relative to neutral images, all *p*s < .0001, while neutral and high-arousal emotional images did not differ , all *p*s > .05. Pr values were higher for high-arousal emotional images compared to low-arousal images, all *p*s < .0001, $\eta^2_p = .32$. Further, discrimination accuracy was comparable for high-arousal emotional images, $F(1,46) = 4.06$, $p = .05$, $\eta^2_p = .08$ (n.s. after Bonferroni correction), while it was reduced for negative/low-arousal images compared to positive/low-arousal images, $F(1,46) = 7.49$, $p = .009$, $\eta^2_p = .14$. With regard to the words, discrimination accuracy did not differ between neutral and low-arousal words, all *p*s > .05. Discrimination accuracy was enhanced for negative/high-arousal words relative to neutral words, $F(1,46) = 40.20$, $p < .0001$, $\eta^2_p = .47$, while it was reduced for positive/high-arousal words relative to neutral words, $F(1,46) = 6.43$, $p = .015$, $\eta^2_p = .34$. Pr values were significantly higher for high-arousal negative than positive words, $F(1,46) = 79.25$, $p < .0001$, $\eta^2_p = .63$, and for negative/low-arousal words relative to positive/low-arousal words, $F(1,46) = 7.47$, $p = .009$, $\eta^2_p = .14$. Negative/low-arousal words were associated with reduced recognition accuracy relative to negative/high-arousal words, $F(1,46) = 36.35$, $p < .0001$, $\eta^2_p = .44$, while Pr values did not differ between low and high-arousal positive words, $F < 1$.

Personality and differential performance. The zero-order correlation coefficients, along with their 95% associated bootstrapped confidence intervals, are reported in Table 7. Pr values did not correlate with positive and negative mood states across affective categories and conditions, all *p*s > .05. Regarding the image recognition condition, BAS-GDP correlated negatively with the Pr values associated with high and low-arousal emotional images. The correlation was significantly greater for positive/low-arousal images relative to negative/low-arousal images ($z = 1.83$, $p = .03$), while the correlation coefficients tended to differ between high-arousal emotional images ($z = 1.51$, $p = .07$). The BIS correlated positively with the discrimination accuracy of neutral and high-arousal positive images, while the FFFS was associated with reduced discrimination accuracy in response to low and high-arousal positive images. With regard to the word recognition condition, the correlation coefficients indicate that BAS-RR (and BAS-tot) correlated negatively with Pr values across affective categories, with the exception of positive/high-arousal words, while Extraversion correlated negatively with Pr values associated with neutral and positive/low-arousal words. BAS-Imp correlated negatively with discrimination accuracy across affective categories, except for low-arousal negative words and high-arousal positive words. In contrast to expectations, no other personality effects were observed, all *p*s > .05.

Table 7. *Zero-order correlations, along with their 95% associated bootstrapped confidence intervals, between personality measures and mood states with Pr values across affective categories.*

Measure	Neutral	Neg-High	Neg-Low	Pos-High	Pos-Low
(1) Image Recognition Condition					
Pos mood	0.23 (-0.06, 0.46)	0.13 (-0.18, 0.43)	0.04 (-0.26, 0.35)	0.02 (-0.30, 0.31)	0.03 (-0.27, 0.32)
Neg mood	0.09 (-0.19, 0.31)	-0.09 (-0.37, 0.20)	-0.05 (-0.35, 0.25)	0.13 (-0.16, 0.36)	0.12 (-0.16, 0.36)
Extraversion	0.16 (-0.18, 0.45)	0.24 (-0.06, 0.52)	0.04 (-0.30, 0.35)	0.13 (-0.22, 0.44)	0.17 (-0.12, 0.45)
Neuroticism	0.17 (-0.11, 0.43)	0.06 (-0.19, 0.30)	0.10 (-0.19, 0.37)	0.19 (-0.11, 0.48)	0.07 (-0.24, 0.38)
BIS	0.35 (0.16, 0.52)*	0.19 (0.00, 0.38)	0.13 (-0.14, 0.41)	0.29 (0.07, 0.50)*	0.16 (-0.10, 0.40)
FFFS	-0.19 (-0.45, 0.10)	-0.12 (-0.45, 0.19)	-0.26 (-0.54, 0.06)	-0.33 (-0.59, -0.06)*	-0.34 (-0.58, -0.08)*
BAS-tot	0.07 (-0.24, 0.32)	-0.11 (-0.43, 0.26)	-0.25 (-0.58, 0.11)	-0.26 (-0.55, 0.06)	-0.31 (-0.62, 0.07)
BAS-RI	0.07 (-0.29, 0.32)	-0.03 (-0.40, 0.34)	-0.09 (-0.46, 0.28)	-0.10 (-0.46, 0.23)	-0.13 (-0.47, 0.22)
BAS-RR	0.18 (-0.11, 0.40)	-0.01 (-0.26, 0.27)	-0.16 (-0.43, 0.12)	-0.17 (-0.45, 0.14)	-0.13 (-0.46, 0.22)
BAS-GDP	0.25 (-0.52, 0.03)	-0.32 (-0.55, -0.05)*	-0.32 (-0.56, -0.04)*	-0.52 (-0.45, 0.19)†	-0.56 (-0.74, -0.33)†
BAS-Imp	0.21 (-0.06, 0.44)	0.03 (-0.32, 0.40)	-0.17 (-0.51, 0.19)	-0.01 (-0.35, 0.34)	-0.11 (-0.42, 0.23)
(2) Word Recognition Condition					
Pos mood	-0.09 (-0.36, 0.19)	-0.23 (-0.45, 0.03)	-0.23 (-0.49, 0.08)	-0.13 (-0.39, 0.15)	-0.26 (-0.52, 0.01)
Neg mood	-0.18 (-0.36, 0.03)	-0.06 (-0.39, 0.19)	-0.09 (-0.35, 0.10)	-0.16 (-0.40, 0.10)	-0.09 (-0.30, 0.08)
Extraversion	-0.32 (-0.51, -0.09)*	-0.13 (-0.40, 0.17)	-0.27 (-0.51, 0.01)	-0.12 (-0.38, 0.19)	-0.30 (-0.52, -0.03)*
Neuroticism	0.01 (-0.25, 0.27)	-0.22 (-0.50, 0.08)	-0.01 (-0.32, 0.28)	-0.05 (-0.34, 0.24)	-0.07 (-0.36, 0.20)
BIS	0.02 (-0.25, 0.29)	-0.18 (-0.46, 0.15)	0.04 (-0.27, 0.35)	-0.07 (-0.38, 0.28)	0.04 (-0.26, 0.33)
FFFS	0.02 (-0.30, 0.34)	-0.19 (-0.48, 0.14)	0.01 (-0.32, 0.33)	0.03 (-0.35, 0.43)	0.01 (-0.33, 0.34)
BAS-tot	-0.35 (-0.60, -0.05)*	-0.39 (-0.64, -0.07)•	-0.40 (-0.60, -0.15)•	-0.19 (-0.50, 0.17)	-0.30 (-0.59, 0.01)
BAS-RI	-0.31 (-0.53, -0.07)*	-0.23 (-0.49, 0.07)	-0.28 (-0.51, 0.02)	-0.13 (-0.39, 0.14)	-0.24 (-0.47, 0.00)
BAS-RR	-0.34 (-0.59, -0.04)*	-0.35 (-0.59, -0.06)*	-0.47 (-0.66, -0.22)†	-0.26 (-0.56, 0.08)	-0.31 (-0.61, 0.01)*
BAS-GDP	-0.09 (-0.39, 0.25)	-0.11 (-0.40, 0.22)	-0.16 (-0.43, 0.14)	0.01 (-0.34, 0.38)	0.04 (-0.32, 0.38)
BAS-Imp	-0.32 (-0.56, -0.06)*	-0.48 (-0.70, -0.21)†	-0.29 (-0.52, 0.02)	-0.20 (-0.46, 0.09)	-0.40 (-0.63, -0.16)•

Note: * $p < 0.05$, • $p < 0.01$, † $p < 0.001$. Pos mood: positive mood, Neg mood: negative mood.

3.5.2 Free Recall

Overall performance. The results of the ANOVA yielded a significant main effect for Emotion, $F(4,188) = 10.82$, $p < .0001$, $\eta^2_p = .19$. Post-hoc comparisons indicated that recall was impaired for neutral words relative to emotional words, all *p*s < .0001, with the exception of negative words low in arousal, $F(1,47) = 2.18$, $p > .05$. Negative/high-arousal words were recalled better than negative/low-arousal words, $F(1,47) = 7.78$, $p = .008$, $\eta^2_p = .14$, whereas recall performance did not differ between positive low and high-arousal words, $F(1,47) < 1$, $p > .05$. Negative/high-arousal words were recalled better than negative/low-arousal words, $F(1,47) = 7.78$, $p = .008$, $\eta^2_p = .14$, whereas recall performance did not differ between positive low and high-arousal words, $F(1,47) < 1$, $p > .05$. Recall performance did not differ for negative and positive high-arousal words, $F(1,47) = 2.54$, $p > .05$, while recall performance was better for positive relative to negative low-arousal words, $F(1,47) = 22.74$, $p < .0001$, $\eta^2_p = .33$.

Personality and differential performance. Zero-order correlations yielded no significant correlations between personality traits and/or mood effects and the number of correctly recalled words across affective categories, all *p*s > .05 (range of *r* coefficients for the personality traits*:* -0.23, 0.25; range of *r* coefficients for the mood states*:* -0.05, 0.27). The correlation coefficients revealed a tendency for increased false recall for BAS-tot ($r = .27$, $p = .06$, CI 95% = 0.00, 0.48).

3.6 Personality, Affective Ratings, and Memory Performance

3.6.1 Image recognition condition

The results of the correlational analyses indicated a relationship between BAS-GDP and valence ratings (except for neutral and positive/low-arousal images) and between BAS-GDP and recognition performance (i.e. hits) and discrimination accuracy (i.e. Pr values), respectively, of emotional images, but not neutral images (see Tables 3, 6, and 7). No significant correlations were observed between hits and valence ratings and between Pr values and valence ratings, respectively, across affective categories (range of *r* coefficients for the hits*:* -0.12, 0.25; range of *r* coefficients for Pr values*:* -0.25, 0.26). Multiple regression analyses were used to examine the hypothesis that BAS-GDP moderated the relationship between valence ratings and subsequent recognition performance and/or discrimination accuracy of emotional images. Separate regression analyses were computed for each emotional category (positive/high-arousal, positive/low-arousal, negative/high-arousal, negative/low-arousal) and for each memory performance index (hit rate, Pr value). Valence rating scores and BAS-GDP scores were entered at Step 1, and the interaction term valence rating x BAS-GDP was entered at Step 2. For the scope of the current study, positive and negative mood scores were not entered in the regression models. Still, regression analyses including mood states yielded the same results. Table 8 summarizes the results of the hierarchical regression analyses. It can be seen that the interaction term valence rating x BAS-GDP was unrelated to performance for positive/low-arousal images. Regarding positive/high-arousal images, the inclusion of the interaction term at Step 2 was significant for hits (Step 1: $R^2 = .26$, $p = .002$; Step 2: $R^2 = .41$, $p < .0001$, $\Delta R^2 = .15$, $p = .002$), but not for Pr values (Step 1: $R^2 = .27$, $p = .001$; Step 2: $R^2 = .27$, $p = .004$, $\Delta R^2 = .00$, $p > .05$). For negative/low-arousal images, the interaction term was significant for Pr values (Step 1: $R^2 = .16$, $p = .022$; Step 2: $R^2 = .29$, $p = .002$, $\Delta R^2 = .14$, $p = .006$), but not for hit rates (Step 1: $R^2 = .07$, $p > .05$; Step 2: $R^2 = .09$, $p > .05$, $\Delta R^2 = .02$, $p > .05$). In contrast, regarding negative/high-arousal images, the valence rating x BAS-GDP interactions tended to be significant for Pr values (Step 1: $R^2 = .10$, $p > .05$; Step 2: $R^2 = .18$, $p > .05$, $\Delta R^2 = .07$, $p = .056$), but not for hit rates (Step 1: $R^2 = .09$, $p > .05$; Step 2: $R^2 = .10$, $p > .05$, $\Delta R^2 = .00$, $p > .05$). Since arousal ratings of high-arousal images, in addition to valence ratings, correlated with BAS-GDP scores (see Table 5), respectively, we performed additional hierarchical regression analyses including the arousal rating scores associated with negative/high-arousal images at Step 1. The results indicated that the interaction term valence rating x BAS-GDP became significant for negative/high-arousal images after controlling for arousal rating scores, but only for Pr values (Step 1: $R^2 = .24$, $p = .009$; Step 2: $R^2 = .33$, $p = .002$, $\Delta R^2 = .09$, $p = .022$) and not for hit rates (Step 1: $R^2 = .28$, $p = .003$; Step 2: $R^2 = .29$, $p = .006$, $\Delta R^2 = .01$, $p > .05$). In Figure 2, a median split of the BAS-GDP scores and valence ratings was used to plot the moderating effect of BAS-GDP on the relationship between valence ratings and subsequent recognition performance (i.e. hits) of positive/high-arousal images and discrimination accuracy (i.e. Pr values) of low and high-arousal negative images. It shows that the recognition performance of high BAS-GDP participants increases as their affective evaluations (i.e. valence ratings) of images increases, while the opposite pattern can be observed for low BAS-GDP participants.

The correlation coefficients in Tables 3, 6, and 7 further indicated significant correlations between FFFS, valence ratings and memory performance (i.e. hits rates and Pr values) of negative/low-arousal images. Hierarchical regression analyses, however, yielded no significant influence of FFFS scores, valence ratings, and the interaction term, respectively, in the prediction of memory performance (i.e. hits and Pr values) of negative/low-arousal images, all *p*s > .05.

Table 8. *Standardized beta coefficients from multiple regression analyses testing the moderator effect of BAS-GDP on the relationship between valence ratings and subsequent recognition performance (hit rates) and discrimination accuracy (Pr values), respectively, of emotional images.*

	Pos-High		Pos-Low		Neg-High		Neg-Low	
Step and variable	Hit	Pr	Hit	Pr	Hit	Pr	Hit	Pr
Step 1								
Valence Rating (VR)	.187	-.023	.108	.076	-.052	-.034	.220	.258
BAS-GDP	-.529†	-.509†	-.474•	-.572†	-.286	-.331*	-.093	-.236
Step 2								
VR x BAS-GDP	4.48•	-.041	.907	-.221	.214	1.298	.780	1.88*

Note: * p < 0.05, • p < 0.005, † p < 0.0001. Pos-High = positive/high-arousal images, Pos-Low = positive/low-arousal images, Neg-High = negative/high-arousal images, Neg-Low = negative/low-arousal images.

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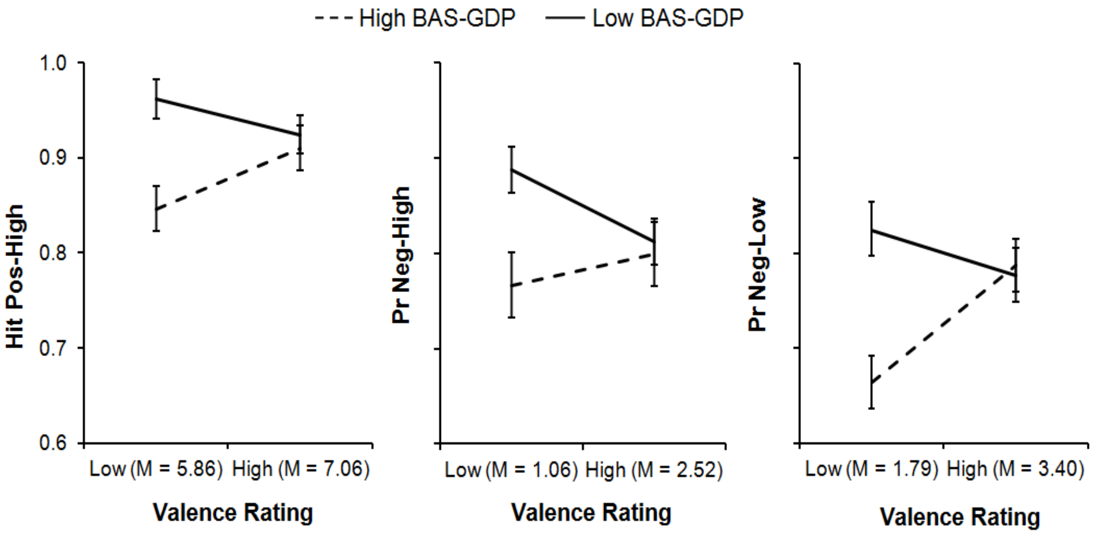


Figure 2. Graph showing the moderating effect of BAS-GDP on the relationship between valence ratings and hite rates for positive/high-arousal (Pos-High) images, and between valence ratings and discrimination accuracy (i.e. Pr values) for negative/high-arousal (Neg-High) images, and negative/low-arousal (Neg-Low) images, respectively.

3.6.2 Word recognition condition

The results of the correlational analyses indicated significant correlations between BAS-tot, BAS-RR, and BAS-Imp, respectively, and arousal ratings and memory performance (hit rates, Pr values) of negative/high-arousal words, respectively (see Tables 4, 6, and 7). In addition, arousal ratings of negative/high-arousal words correlated negatively with the Pr values associated with negative/high-arousal words (r = -.37, p = .01, CI 95% = -0.60, -0.13). Multiple regression analyses, following the steps suggested by Baron & Kenny (1986), were used to examine the hypothesis that arousal ratings associated with negative/high-arousal words mediated the influence of BAS-tot, BAS-RR, and/or BAS-Imp on the recognition performance (hits) and accuracy (Pr values) of negative/high-arousal words. The results of the multiple regression analyses for each model are presented in Table 9. No mediator effects were obtained with regard to hit rates. Results indicated that arousal ratings associated with negative/high-arousal words mediated the relationship between BAS-RR and discrimination accuracy (old vs. new) of negative/high-arousal words, but no mediator effects were obtained for BAS-tot and BAS-Imp. BAS-RR no longer predicted recognition accuracy after controlling for the mediator, β = -.26, t(46) = -1.83, p = .07, thus indicating complete mediation. The meditational model accounted for 20% of the variance in the recognition accuracy for negative/high-arousal words (R^2 = .201, p = .007). A bootstrap method with 1000 samples was used to test the statistical significance of the indirect effect (Shrout & Bolger, 2002) which was significant, β = -.09, SE = .04, CI 95% = -.19, -.02. Thus, higher BAS-RR scores were associated with a reduction of 9 % in discrimination accuracy of negative/high-arousal words as mediated by the participants' arousal ratings associated with negative/high-arousal words. Figure 3 shows the mediating effect of arousal ratings associated with negative/high-arousal words on the relationship between BAS-RR and discrimination accuracy (i.e. Pr values) of negative/high-arousal words. A median split of the arousal ratings was used in Figure 3a to plot the mediator effect. It can be seen that higher BAS-RR scores were linked to higher arousal ratings of negative/high-arousal words, which then impaired discrimination accuracy, especially for negative/high-arousal words rated low in arousal.

The correlation coefficients in Tables 4, 6, and 7 further showed a relationship between BAS-RR, arousal ratings and memory performance (i.e. hit

Table 9. *Results of the test for mediation using a four step approach with several regression analyses.*

		Hit			Pr		
Criterion	Predictor	B	*SE* B	*β*	B	*SE* B	*β*
(1) Model 1: BAS-tot							
Step 1							
Hit/Pr Neg-High	BAS-tot	-.003	.001	-.361*	-.003	.001	-.387•
Step 2							
Arousal Rating	BAS-tot	.043	.019	.325*	.043	.019	.325*
Step 3 and 4							
Hit/Pr Neg-High	BAS-tot	-.002	.001	-.280	-.002	.001	-.296*
	Arousal Rating	-.015	.009	-.251	-.017	.008	-.278
(2) Model 2: BAS-RR							
Step 1							
Hit/Pr Neg-High	BAS-RR	-.007	.003	-.317*	-.008	.003	-.348*
Step 2							
Arousal Rating	BAS-RR	.111	.052	.303*	.111	.052	.303*
Step 3 and 4							
Hit/Pr Neg-High	BAS-RR	-.005	.003	-.235	-.006	.003	-.259
	Arousal Rating	-.016	.009	-.270	-.018	.008	-.296*
(3) Model 3: BAS-Imp							
Step 1							
Hit/Pr Neg-High	BAS-Imp	-.011	.003	-.459†	-.011	.003	-.482†
Step 2							
Arousal Rating	BAS-Imp	.129	.056	.322*	.129	.056	.322*
Step 3 and 4							
Hit/Pr Neg-High	BAS-Imp	-.009	.003	-.390*	-.010	.003	-.403†
	Arousal Rating	-.013	.008	.216	-.015	.008	-.245

Note: * $p < 0.05$, • $p < 0.01$, † $p < 0.005$. Neg-High = negative/high-arousal words.

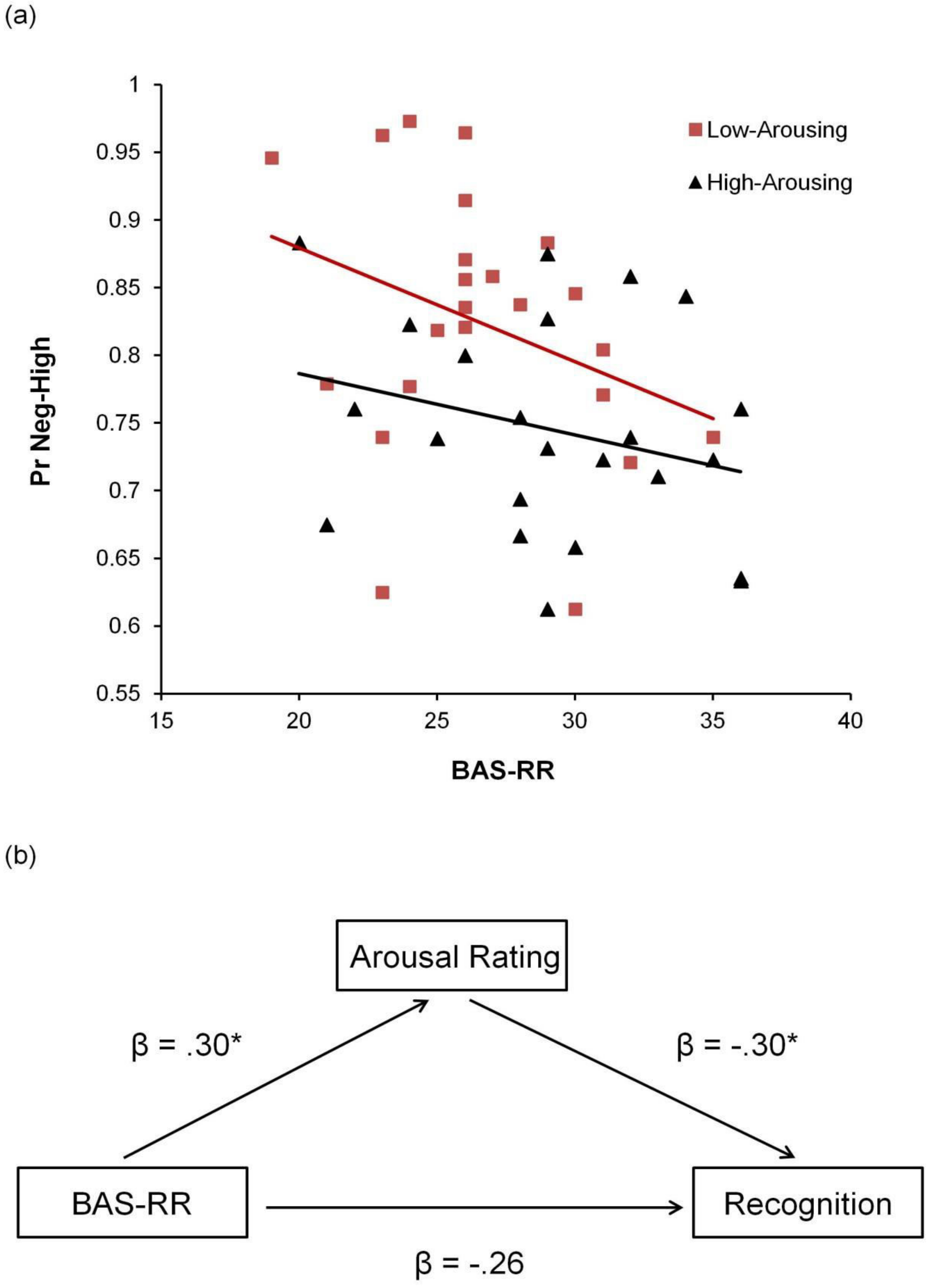


Figure 3. (a) Graph showing the mediator effect of arousal ratings on the relationship between BAS-RR and discrimination accuracy (i.e. Pr) of negative/high-arousal (Neg-High) words. (b) Graph showing the mediatior effect for negative/high-arousal words. The standardized beta coefficient regarding the influence of BAS-RR on recognition performance were computed while controlling for arousal ratings associated with negative/high-arousal words and the beta weight of the effect between arousal ratings and recognition of arousing, negative words was computed while BAS-RR was controlled for. Note: * $p < 0.05$.

rates and Pr values) of negative/low- arousal words. The results of the regression analyses yielded an influence of BAS-RR in the prediction of discrimination accuracy of negative/low-arousal words, but arousal ratings and the interaction term yielded no significant effects in the prediction of memory performance (all *p*s > .05).

In addition, the results of the correlational analyses demonstrated significant correlations between extraversion and valence ratings and discrimination accuracy (i.e. Pr values), respectively, of positive/low-arousal images (see Table 3 and Table 7). Hierarchical regression analyses, however, demonstrated no significant influence of extraversion scores, arousal ratings, and the interaction term, respectively, in the prediction of memory performance (i.e. Pr values) of positive/low-arousal words, all *p*s > .05.

3.6.3 Word recall condition

No moderator or mediator effects were observed, all *p*s > .05.

4. Discussion

The present study investigated Eysenck's and Gray's personality dimensions in emotional information processing and it further explored moderator and mediator effects between personality traits, affective evaluations, and memory performance. The results demonstrated differential trait congruency effects between stimuli (words vs. images), between valence and arousal ratings, and between different indices of memory performance (proportion of correct responses, false alarms, discrimination accuracy). More importantly, individual differences in Reward sensitivity (i.e., BAS-GDP) moderated the relationship between valence ratings and memory performance for images, while arousal ratings mediated the relationship between individual differences in Reward sensitivity (i.e., BAS-RR) and memory performance for words.

Overall, the results across the emotional processing tasks provide evidence for trait-congruency effects with regard to Gray's personality theory (i.e., BAS, BIS, FFFS), while little support was obtained for the involvement of Eysenck's personality dimensions (i.e., extraversion and neuroticism). Extraversion correlated positively with the valence ratings of positive/low-arousal words, but only in the word recognition condition. This observation is in line with previous research showing that extraversion associated with the susceptibility for positive stimuli (e.g., De Pascalis et al., 2000; Gomez et al., 2002; Larsen & Ketelaar, 1991; Rafiena et al., 2008; Rusting; 1999; Rusting & Larsen, 1998). False alarms for neutral and negative/low-arousal words correlated positively with extraversion scores, a finding that corresponds to the results of prior studies that have linked extraversion to susceptibility of false memories (Frost, Sparrow, & Barry, 2006; Porter, Birt, Yuille, & Lehman, 2000). Further, the observed enhanced memory performance for neutral and positive/low-arousal words for introverts relative to extroverts, is likely to reflect the need to reduce arousal levels among introverts to avoid sensory overstimulation and thus to approach their optimal level of arousal. Extraverts, on the other hand, prefer sensory stimulations that increase their cortical arousal levels (Eysenck, 1967). Contrary to expectations, positive/high-arousal stimuli failed to show a relationship with extraversion across emotional processing tasks. These null findings could be indicative of a ceiling effect due to the high arousal value of the stimulus, resulting in strong affective reactions in both introverts and extraverts. Neuroticism did not correlate with the emotional processing tasks across conditions, except for a negative correlation with the valence ratings for positive/high-arousal images in the image recognition condition. Although this result is not unexpected and in line with previous reports showing a negative relationship between neuroticism and emotional information processing of positive stimuli (Leikas & Lindeman, 2009; Rafiena et al., 2008; Rusting, 1999), the general lack of correlations of neuroticism with negative stimuli in the current study is in contrast with previous findings, employing natural mood states, showing that neuroticism is associated positively with the emotional information processing of negative material (e.g., Gomez et al., 2002; Martin et al., 1983; Ruiz-Caballero & Bermúdez, 1995; Rusting; 1999; Rusting & Larsen, 1998; Young & Martin, 1981), even though inconsistencies have been reported in previous studies (for a review see Rusting, 1998).

The results with regard to Gray’s theory show a more detailed pattern and they provide support for the revised RST (Gray & McNaughton, 2000), by showing that the FFFS mediates responses towards negative stimuli, but not the BIS. In contrast, the BIS correlated positively with valence ratings and memory performance for neutral images. This finding is likely due to the increment in attention to non-rewarding stimuli associated with the BIS (e.g., Gray, 1987). In addition, the BIS correlated negatively with false alarms and positively with the discrimination accuracy of positive/high-arousal images. Since the positive correlation between BIS and memory performance for positive/high-arousal images was obtained only with regard to discrimination accuracy, but not with regard to the hits, this unexpected result is probably the result of reduced false alarms due to the output of the BIS being an increase in attention, which then resulted in better discrimination between new and old stimuli. The results with regard to the BAS show a somewhat different pattern between the use of total BAS scores and BAS subscales (RR, RI, GDP, Imp). Greater BAS total scores, BAS-RR, and BAS-GDP were related to an enhanced negative evaluation of negative stimuli and to an enhanced positive evaluation of positive stimuli, regardless of the arousal value. The relationship between BAS-Imp and BAS-RI, respectively, and valence ratings was restricted to positive/high-arousal images. Overall, these findings support the notion that the BAS is sensitive to rewarding stimuli (e.g., Gray, 1970, 1981; Gray & McNaughton, 2000) and the results are in line with previous findings showing that the BAS is positively associated with information processing of positive stimuli (Gomez & Gomez, 2002; Gomez et al., 2004; Zelenski & Larsen, 2002). BAS total scores and BAS subscales further correlated positively with the arousal ratings for negative/high-arousal stimuli. The observation that valence and arousal ratings of low and high-arousal negative stimuli are modulated by individual differences in reward sensitivityis in accordance with prior research (Balconi, Falbo, & Brambilla, 2009) and it supports the notion that negative emotions (i.e. anger) or stimuli can evoke approach motivation (e.g., Harmon-Jones, Harmon-Jones, & Price, 2013). Contrary to expectations and previous studies (Gomez & Gomez, 2002; Gomez et al., 2004), no trait congruency effects were observed with regard to emotional memory. The results merely yielded negative correlations between BAS and BAS subscales, respectively, and memory performance for negative (and positive) stimuli. While the negative correlation between BAS-Imp and memory performance for positive words is not unanticipated, the negative correlation between BAS-GDP and memory performance for low and high-arousal positive images was unforeseen. Based on the increased sensitivity for positive stimuli (e.g., Gray, 1970, 1981; Gray & McNaughton, 2000), one would expect a positive relationship between BAS and memory performance for positive stimuli. As will further be discussed in the next paragraph, the observed moderator effect for BAS-GDP helps to explain this result. Although the results suggest a differential pattern among BAS subscales, it is important to note that the correlation coefficients did not differ between the subscales. This implies that BAS components do not differentially affect emotional information processing. Since studies are scarce (e.g., Balconi et al., 2009; De Pascalis, Fracassao, & Corr, 2017), more research is needed that examines possible differences between BAS components in emotional information processing tasks. This way one will be able to gain a better understanding of the multidimensional nature of the BAS.

More importantly, the results of the current study provide evidence for moderator and mediator effects in emotional information processing. BAS-GDP moderated the relationship between valence ratings and hits of positive/high-arousal images and discrimination accuracy of negative low and high-arousal images, respectively. Recognition performance of high BAS-GDP individuals increased as their affective evaluations (i.e., valence ratings) of positive/high-arousal images increased, while enhanced negative evaluations of negative images resulted in impaired recognition memory for negative images in high BAS-GDP individuals. The opposite pattern emerged for low BAS-GDP individuals. Associated valence ratings did not predict subsequent memory performance on their own, rather the results suggest that the interaction with personality effects (i.e., BAS-GDP) was necessary to yield the influence of valence ratings on memory performance. Goal-drive persistence refers to the motivation to achieve goals (i.e. obtaining a reward) and to the maintenance of motivation over time, especially in the absence of instant reward (Corr & Cooper, 2016). Hence, the observation that BAS-GDP moderated the relationship between valence ratings and recognition memory is likely due to the drive and persistence associated with the task performance, especially pertaining to appetitive, high-arousal positive images. In the word recognition condition, arousal ratings mediated the relationship between BAS-RR and discrimination accuracy of negative/high-arousal words. Higher BAS-RR scores predicted higher arousal ratings of negative/high-arousal words, which then impaired discrimination accuracy for those words. Assuming that negative stimuli can elicit approach-motivated behavior (e.g., Harmon-Jones et al., 2013), this may explain why the influence of BAS on arousal ratings was restricted to negative/high-arousal words. However, the subsequent impaired recognition memory implies that approach motivation did not facilitate recognition memory for the negative stimulus. Although emotional arousal has been shown to facilitate consolidation of memory traces, and thus long-term retention (e.g., McGaugh, 2004), previous research regarding eyewitness memory has shown that high levels of emotional arousal can impair memory for the traumatic event (e.g., Christianson, 1992). Given that the BAS mediates approach behavior and active avoidance of punishment cues (e.g., Gray, 1970, 1981, 1987), the inability to avoid the negative, arousing stimulus could have resulted in increased distress and subjective experience of arousal, which then weakened, rather than strengthened, the memory for the aversive stimulus. It is important to note that the results regarding BAS-tot and BAS-Imp yielded a trend towards partial mediation, but not complete mediation, as observed for BAS-RR. Since the sample size in the current study is rather small, but nevertheless sufficient for performing moderator and mediator analyses, increasing the sample size could therefore have yielded partial mediation effects for BAS-tot and BAS-Imp. The increased sensitivity to reward and pleasure associated with BAS-RR (Corr & Cooper, 2016) conflicts with the aversive nature of negative/high-arousal words, which may explain why complete mediation was observed for BAS-RR, but nor for other BAS facets.

In contrast to expectations and previous findings (e.g., Bradley et al., 1993; Bradley & Mogg, 1993; Martin & Ward, 1983; Rusting; 1999; Rusting & Larsen, 1998), no trait-congruency effects were observed with regard to the word recall condition, except for a tendency for increased false recall regarding the BAS. It should be noted that the word recall condition and word recognition condition cannot be readily compared due to the different number of word stimuli used for calculating mean valence and arousal ratings. However, since the analyses failed to reveal significant differences in valence and arousal ratings between the two conditions, it seems unlikely that the nonsignificant personality effects with regard to the word recall condition are due to affective differences in the stimulus material between the conditions. The word stimuli employed in the current study had an overall low frequency of use. Word frequency has been shown to differentially influence recall and recognition: low-frequency words are recognized better than high-frequency words, whereas high-frequency words are recalled better than low-frequency words (e.g., Gregg, 1976). Correspondingly, recall performance of words was greatly reduced in the current study relative to recognition performance. Recall is more difficult than recognition because it requires more active reinstatement of the learned material - an inherent difference between recall and recognition (e.g., Gillund & Shiffrin, 1984). Thus, it is possible that the greater task difficulty of the recall task together with the large number of word stimuli impeded the influence of personality effects.

Few studies have directly compared images and words in relation to affective processing (Bayer & Schacht, 2014; De Houwer & Hermans, 1994; Hinojosa et al., 2009; Kensinger & Schacter, 2006; Schlochtermeier et al., 2013; Tempel et al., 2013). The results of the current study show differences between images and words with regard to affective ratings and memory performance for the affective material (hits, false alarms, and discrimination accuracy). A number of discrepancies with the results of previous studies should be noted. While the results of the affective rating task indicated that negative/low-arousal images were rated as more unpleasant and arousing than negative/low-arousal words, and that neutral words were rates as more pleasant than neutral images, other studies failed to find differences in affective evaluations between pictures and words (Tempel et al., 2013) or they observed that differences in affective evaluations between pictures and words were restricted to positive stimuli (Bayer & Schact, 2014; Schlochtermehier et al., 2013). It is possible that differences in stimulus material, such as arousal level, word class (noun, adjective, verb), and word frequency, are accountable for the conflicting results. The results provide support for a picture superiority effect, as reflected by better memory performance for images compared to words (e.g., Paivio & Csapo, 1973). More importantly, the current study presents evidence that emotional content differentially impacts item recognition memory for words and images, in contrast to the null results when employing a source memory paradigm (Kensinger & Schacter, 2006). The arousal value of the stimulus (high vs. low) influenced the processing (i.e. affective ratings, memory performance) of words and pictures in a different way. With the exception of one study (Hinojosa et al., 2009), previous research did not manipulate the arousal value of the stimulus material when comparing pictures and words in relation to emotional information processing. The results of the current study, however, show that the manipulation of arousal value provides a more detailed pattern of the interplay between valence and arousal on processing differences between pictures and words. The necessity to manipulate the arousal value of the stimuli in future studies is further supported by the observation that emotional valence was linked to moderator effects for images, while emotional arousal was linked to mediator effects for words.

In accordance with previous research that did not manipulate mood states (Gomez & Gomez, 2002; Gomez et al., 2002; Rusting, 1999; Rusting & Larsen, 1998; Zelenski & Larsen, 2002), our results showed little influence of positive and negative mood states on task performance. The influence of mood states was limited to the affective rating task, especially with regard to the valence ratings, and mood effects were obtained only for positive mood states, but not negative mood states. We did not consider mood states in the moderator and mediator analyses since the primary aim of the current study was to examine the influence of trait-congruency effects for affective evaluations on subsequent memory performance. Further, including mood states in the regression analyses did not differentially influence the results.

To conclude, the results of the current study provide support for the revised RST (Gray & McNaughton, 2000). The results of the present study urge future studies, employing multiple emotional information processing tasks, to take into account possible relationships between tasks when examining trait-congruency effects. This will help to gain a better understanding of the trait processes underlying trait-congruency effects in emotional information processing.

Chapter 3

The Role of Fear and Impulsivity in Exogenous Attention to Emotional Stimuli as Indexed by the Early Posterior Negativity and Late Positive Potential

This chapter is based on: Sommer, K., & De Pascalis, V. (in preparation). The role of fear and impulsivity in exogenous attention to emotional stimuli as indexed by the early posterior negativity and late positive potential.

Abstract

Emotional stimuli capture attention more readily than neutral stimuli, even when attentional resources are limited, suggesting that the emotion modulation of attentional allocation occurs rather automatically. The present study investigated whether exogenous attention to emotional stimuli, as indexed by the early posterior negativity (EPN) and late positive potential (LPP), is differentially influenced by underlying differences in the behavioral approach system (BAS) and its facets, the flight-fight-freeze system (FFFS), and the behavioral inhibition system (BIS), of the reinforcement sensitivity theory of personality (RST). Participants viewed neutral and emotional images that differed in arousal level to examine valence-arousal interactions in exogenous attention to emotional stimuli. On half of the trials, attentional resources were manipulated by having participants perform a visual detection task on emotional and neutral words that were presented successively in the surroundings of the image. The results suggest that exogenous attention is driven by the valence-arousal interactions with regard to the EPN, while it is driven by the arousal value of the stimulus with regard to the LPP. More importantly, the FFFS correlated negatively with EPNs elicited by negative images and negative words presented during directed attention trials. Impulsivity was associated negatively with LPP amplitudes elicited by negative and positive low-arousal images and positive words when attention was directed away from the affective image. Results are discussed within the revised RST framework that differentiates fear from anxiety and reward components from impulsivity.

1. Introduction

Emotions guide attention through bottom-up and top-down mechanisms. Due to their evolutionary significance, negative and threatening stimuli are detected faster than neutral or positive stimuli, thus biasing attentional selection based on physical saliency (bottom-up; e.g., Öhman, & Mineka, 2001; for a review see Mohanty & Sussman, 2013). Top-down mechanisms, such as task goals and reward contingencies, are able to further modulate the bottom-up control of attention by emotion (e.g., Mohanty & Sussman, 2013).

Event-related potential (ERP) studies examining the influence of emotions on attentional processes during perceptual processing have shown a differential modulation of early and late ERP waveforms between emotional and neutral stimuli. Based on ERP difference waves, electrophysiological studies have identified two components that index greater allocation of attentional resources towards emotional relative to neutral stimuli: the early posterior negativity (EPN) and the late positive potential (LPP). The EPN refers to an increased negativity for emotional relative to neutral stimuli over temporal-occipital regions (and an increased positivity over fronto-central regions) from approximately 200 - 300 ms after stimulus onset. It has been suggested that the EPN indexes the call for attentional resources and that it represents an early marker of selective processing of emotional stimuli. The LPP refers to an increased positivity for emotional relative to neutral stimuli over centro-parietal regions from approximately 400 - 800 ms after stimulus onset. The affective influences on LPP amplitudes are assumed to indicate enhanced attention towards and increased perceptual processing of emotional relative to neutral stimuli (for reviews see Olofsson, Nordin, Sequeira, & Polich, 2008; Schupp, Flaisch, Stockburger, & Junghöfer, 2006).

Several studies have investigated whether the facilitated processing of emotional stimuli occurs automatic or whether it requires attentional resources. Exogenous (i.e. automatic) attentional mechanisms to emotional stimuli have been studied through the use of *directed attention tasks* (MacNamara, Kappenman, Black, Bress, & Hajcak, 2013), which have also been referred to as *concurrent but distinct target-distractor* (CDTD) *paradigms* (Carretié, 2014). In directed attention tasks, participants are instructed to ignore emotional distracting stimuli while focusing the attention on other stimuli that are concurrently presented in a different location (e.g., an emotional image is presented at the center of the screen while the participants perform a letter identification task on letters that are presented on top of and below the image). Results of fMRI studies, showing that amydala activity is unaffected by attentional manipulations (e.g., Anderson, Christoff, Panitz, De Rosa, & Gabrieli, 2003; Fichtenholz et al., 2004; Vuilleumier, Armony, Driver, & Dolan, 2001), suggest that the prioritized processing of emotional stimuli occurs rather automatic and independent of the available attentional resources. However, this view has been challenged by the observation that amydala activity is absent in response to task-irrelevant emotional distractors when participants perform an attentional demanding primary task (Pessoa, McKenna, Gutierrez, & Ungerleider, 2002; Pessoa, Padmala, & Morland, 2005; Silvert et al., 2007). These results are in line with Lavie's load theory of attention and cognitive control (e.g., Lavie, 2005, 2010), which states that the ability to focus attention and thus to ignore task-irrelevant distractors is enhanced under conditions of high perceptual load, whereas it deteriorates when high load is imposed on cognitive control processes, such as working memory, for instance.

Several ERP studies have shown that when attention is directed away from the emotional stimulus, the emotional effects on the EPN and LPP are eliminated (e.g., De Cesarei, Codispoti, & Schupp, 2009; Eimer, Holmes, & McGlone, 2003; Holmes, Kiss, & Eimer, 2006; MacNamara & Hajac, 2009) or they remain preserved but reduced (Hajcak, Dunning, & Foti, 2007; Sand & Wiens, 2011; Wiens, Sand, Norberg, & Andersson, 2011). A recent study examined the combined effects of valence and arousal levels on attentional effects in emotional processing (Wiens & Syrjänen, 2013). The strong liner increase in EPNs as a result of the arousal value when attention is directed towards the emotional stimulus decreases when attention is directed towards the primary task, even though this effect was stronger for positive than negative images. In addition, the linear effect of arousal on LPP amplitudes is reduced when attention is directed away from the emotional stimulus, but only for positive and not for negative images. Using an emotional primary task, it has further been shown that the affective modulation of LPP amplitudes by the emotional target stimulus is not further influenced by the affective content of the distractor stimulus: negative images elicited greater LPP amplitudes than neutral images, regardless of whether concurrent neutral or negative distractor images were presented (MacNamara & Hajac, 2009). The aforementioned studies directed attention by either presenting the emotional distractor stimuli or the primary target stimuli in the periphery of the visual field. Research has shown that emotional distractors presented at fixation elicit larger EPN and LPP amplitudes than emotional stimuli presented in the periphery (De Cesarei et al., 2009). Indeed, evidence indicates that exogenous attentional mechanisms to emotional stimuli differ between tasks that present the emotional distractor stimuli around the neutral primary task, or vice versa, and for tasks that present the primary task on top of the emotional distractor stimulus (Nordström & Wiens, 2012). For emotional scenes, EPN amplitude differences between negative and neutral stimuli increase when the primary task and emotional distractors is presented concurrently but separately. In contrast, the LPP amplitude difference between negative and neutral images are greater when the primary tasks is superimposed onto the distractor, but this effect has been found to be unrelated to stimulus differences (scenes vs. figures). Studies that overlaid the emotional distractors with the primary task observed that negative distractor stimuli elicit increased EPNs and LPP amplitudes relative to neutral distractor stimuli (Schönwald & Müller, 2014) and while emotional images continued to elicit greater LPP amplitudes than neutral images when attention is directed towards the overlaid primary task, positive images no longer elicit greater LPP amplitudes relative to negative images (Wangelin, Löw, McTeague, Bradley, & Lang, 2011). Further, the arousal value of negative stimuli (neutral, medium, high) does not differentially impact EPNs when attention is directed towards the overlaid primary task, whereas the enhanced LPP amplitudes for negative, arousing relative to neutral stimuli is absent during directed attention trials (Nordström & Wiens, 2012; Wiens, Molapour, Overfeld, & Sand, 2012). Studies investigating the influence of perceptual load on the attentional influences on emotion modulation of EPN and LPP amplitudes have produced inconsistent results. ERP studies have shown that under conditions of high load emotional images fail to elicit an emotion modulation of the EPN relative to neutral images (Müller-Bardorff et al., 2016; Schupp, Stockburger, Bublatzky, Junghöfer, Weike, & Hamm, 2007), while other studies failed to find an influence of perceptual load on selective attention to emotional stimuli with regard to the LPP and EPN (Wiens et al., 2012; Müller-Bardorff et al., 2016). The modulatory influence of the arousal value on the EPN and LPP has further been found to be unaffected by the perceptual load of the primary task (Müller-Bardorff et al., 2016). In addition, no effect of task load on attentional modulations of the EPN has been observed when the primary task taps the auditory modality rather than the visual modality (Schupp, Stockburger, Bublatzky, Junghöfer, Weike, & Hamm, 2008). Overall, the results suggest that emotion modulation of ERP components remains preserved when emotional distractors are presented at fixation, but not when presented in the periphery, and that exogenous attention to emotional stimuli is driven by the arousal dimension. However, with the exception of few studies (Müller-Bardorff et al., 2016; Wiens & Syrjänen, 2013), the majority of studies compared neutral with high-arousal negative stimuli (and to a lesser extent with high-arousal negative and positive stimuli), leaving unknown the relative contribution of valence and arousal levels.

Attentional biases towards affective stimuli are not only influenced by the affective content of the stimulus, but also by individual state-trait characteristics. Gray's reinforcement sensitivity theory (RST) of personality (Gray, 1970, 1981, 1987; Gray & McNaughton, 2000) posits that individual differences in motivational approach-avoidance systems determine affective reactions to emotional stimuli. The revised RST (e.g., Gray & McNaughton, 2000) explains individual differences in responding to punishing and reinforcing stimuli in terms of underlying differences in three major brain systems: the behavioral approach system (BAS), the flight-fight-freeze system (FFFS), and the behavioral inhibition system (BIS). The BAS is responsive to appetitive signals of reward and nonpunishment (active avoidance), its activation elicits active approach behavior and results in the experience of positive affect. The FFFS has been related to the emotion fear and it is activated in response to signals of threat and punishment, with the consequence of emerging escape and avoidance behaviors. The BIS is activated by signals of punishment, nonreward, and novelty, and by goal-conflicting stimuli (i.e. approach-avoidance conflict that is caused by the co-activation of the BAS and FFFS), and its activation results in the inhibition of ongoing behavior, in increased attention and arousal, and in the experience of negative affect. The influence of the BAS, FFFS, and BIS on exogenous attention to emotional stimuli is unknown. Previous research in clinical populations has shown that individuals with generalized anxiety disorder, compared to healthy controls, show greater behavioral interference by aversive distractors (MacNamara & Hajcak, 2010) and that patients suffering from schizophrenia, compared to healthy controls, exhibit greater interference by positive relative to neutral and negative distractor faces (Grave, Soares, Morais, Rodrigues, & Madeira, 2017). Attentional biases in exogenous attention have also been noted in specific anxiety disorders, such as blood phobia (Buodo, Sarlo & Munafò, 2010), and spider phobia (Straube, Mentzel & Miltner, 2006). Studies that examined the influence of personality traits on exogenous attention to emotional stimuli have primarily focused on (social) anxiety. Under conditions of high perceptual load individuals high in social anxiety show increased interference by distractor stimuli compared to individuals low in social anxiety, but not if attention is focused on pictures of people in the primary task (Moriya &Tanno, 2010, 2011). Using threatening stimuli rather than non-emotional stimuli, it has been observed that the interference effects in individuals high in social anxiety are greater for negative distractor faces compared neutral and positive distractor faces (Soares, Rocha, Neiva, Rodrigues, & Silva, 2015). It has further been shown that high and low anxious participants do not show differential amygdala activity to fearful faces under high perceptual load. Under low perceptual load, heightened activity in the amygdala to fearful faces has been associated with elevated state anxiety, whereas elevated trait anxiety has been associated with reduced activity in frontal brain regions (Bishop, Jenkins, & Lawrence, 2007). This indicates that trait anxiety is associated with increased interference by distractors due to reduced involvement of prefrontal attentional control mechanisms - even in the absence of threat-related stimuli (Bishop, 2009). The aforementioned results indicate that exogenous attention to emotional stimuli is modulated by individual state-trait characteristics. Since the RST systems have been related to psychopathology (Bijttebier, Beck, Claes, & Vandereycken, 2009; Clark, 2005) and since the BIS is associated with the anxiety personality dimension (e.g., Gray & McNaughton, 2000), for instance, it seems reasonable to assume that underlying differences in the three neurobiological systems modulate exogenous attention to emotional stimuli.

Therefore, the present study aimed to investigate whether exogenous attention to emotional stimuli, as indexed by the EPN and LPP, is modulated by underlying differences in the RST systems (i.e., BAS, FFFS, and BIS). To this end, participants viewed neutral images and emotional images that differed in arousal level (high vs. low), to further examine the relative contribution of valence and arousal on exogenous attention. The images were either passively viewed or the participants performed a visual detection task on emotional and neutral words that were presented one after another in the surroundings of the images. Prior studies mainly used either emotional distractor stimuli or emotional target stimuli. In the current study, not only the distractors but also the target stimuli were emotional to examine distractor interferences in relation to affective processing of stimuli that are presented in attended locations, regardless of the affective content of the distractor image. Based on existing work it was expected that when attention is directed away from the emotional image, emotional images no longer elicit enhanced EPNs and LPP amplitudes relative to neutral stimuli, especially with regard to low-arousal but not high-arousal emotional images. We further anticipated that images presented with negative and positive words elicit reduced EPNs and LPP amplitudes in response to the image relative to neutral words. Regarding the influence of the RST systems on exogenous attention to emotional stimuli, it was expected that the FFFS and BIS are linked to increased interference (i.e. enhanced EPNs and LPP amplitudes) by negative images when attention is directed towards the emotional words, whereas the BAS was expected to be linked to increased interference by positive images. Finally, the FFFS and BIS were hypothesized to be associated with increased processing of negative words, resulting in reduced interference by the distractor images (i.e. reduced EPNs and LPP amplitudes) when they were simultaneously presented with negative words, while the BAS was expected to be associated with increased processing of positive words. Since the BAS is multidimensional (e.g., Corr, 2008; Corr & Cooper, 2016), we further explored differences between BAS facets in exogenous attention to emotional stimuli.

2. Method

2.1 Participants

A total of 104 psychology students from the La Sapienza University of Rome participated for course credit. Four participants were excluded due to excessive artifacts in the EEG, which left an insufficient number of epochs for averaging (< 16 artifact free epochs). Hence, the final sample considered for analysis consisted of 100 participants (76 females, 24 males) ranging in the age from 21 to 34 years (*M* = 24.1, *SD* = 2.57). Participants reported neither history of neurological or psychiatric disorders, nor usage of certain medications and drugs that might interfere with the EEG recordings. Female students participated in the experiment outside of their menstrual period. Each participant gave written consent and the study was approved by the local ethics board.

2.2 Questionnaires

Reinforcement Sensitivity Theory Personality Questionnaire. The Reinforcement Sensitivity Theory Personality Questionnaire (RST-PQ; Corr & Cooper, 2016) is based on the revised RST (e.g., Gray & McNaughton, 2000). The RST-PQ was used as a measure of the Behavioral Inhibition System (BIS), the Fight-Flight-Freeze System (FFFS), and four Behavioral Approach System (BAS-tot) factors, which are taken into account in the current study: Reward Interest (RI), Goal-Drive Persistence (GDP), Reward Reactivity (RR), and Impulsivity (Imp). In total, the RST-PQ comprises 73 statements about everyday feelings and behaviors (e.g., "I find myself doing things on the spur of the moment.") that ask the respondents to specify how accurately each statement depicts them. Each item is rated on a 4-point Likert scale, ranging from 1 (not at all) to 4 (highly).

2.3 Experimental Task: Stimuli and Design

2.3.1 Stimuli

Images. A total of 600 images (120 positive/low-arousal images, 120 positive/high-arousal images, 120 negative/low-arousal images, 120 negative/high-arousal images, and 120 neutral images) were selected from the International Affective Picture System (Lang, Bradley, & Cuthbert, 2008) and from the Geneva Affective Picture Database (Dan-Glauser & Scherer, 2011). Affective ratings, obtained from 28 students, were used for the selection of the words, using a 9-point Likert scale, ranging from 1 (*negative valence* or *low arousal*) to 9 (*positive valence* or *high arousal*). An analysis of variance (ANOVA) on the valence ratings revealed a main effect for valence, $F(4,599) = 2772.13$, $p < .0001$. Post-hoc comparisons indicated that valence ratings differed across emotional categories, all *p*s < .0001, with the exception of low and high-arousal positive images, $p = .38$. Further, the ANOVA on the arousal ratings yielded a main effect of arousal, $F(4,599) = 871.79$, $p < .0001$. Emotional images were rated as more arousing than neutral images, all *p*s < .0001, and high-arousal emotional images were rated as more arousing than low-arousal emotional images, all *p*s < .0001. Negative/high-arousal images were rated more arousing than positive/high-arousal images, $p < .0001$, and negative/low-arousal images were rated more arousing than positive/low-arousal images, $p < .0001$. The images were distributed into two sets of 300 images each (60 positive/low-arousal images, 60 positive/high-arousal images, 60 negative/low-arousal images, 60 negative/high-arousal images, and 60 neutral images). The participants were randomly assigned to one to the two sets. No significant differences were observed between the sets with regard to normative valence and arousal ratings across affective categories, all *p*s > .05.

Words. The word set consisted of 600 words (verbs, adjectives, and nouns) that were selected from an Italian dictionary (De Mauro, Mancini, Vedovelli, & Voghera, 1993). Affective ratings, obtained from 64 students, were used for the selection of the words, using a 9-point Likert scale, ranging from 1 (*negative valence* or *low arousal*) to 9 (*positive valence* or *high arousal*). The final word set comprised 200 positive (*M* = 6.78, *SD* = .48), 200 negative (*M* = 3.07, *SD* = .59), and 200 neutral words (*M* = 5.00, *SD* = .49), that differed in normative valence ratings, all *p*s < .0001. Word length ranged from four to seven characters, they comprised one to three syllable words, and the overall frequency of use was low (*M* = 4.37, *SD* = 6.74). There were no significant differences in word length and frequency of use between the affective word conditions (i.e., neutral, positive, negative), all *p*s > .05.

2.3.2 Trial Structure

Figure 1 shows a schematic of the trial structure. The experimental task contained two different types of trials: full attention (FA) and divided attention (DA) trials. Each trial started with the presentation of a fixation cross for 500 ms, which was followed by the presentation of a neutral or emotional image for a duration of three seconds. To ensure that the participants attended to the presented material, they were instructed to make an approach/avoidance in response to the presented material after the offset of each image (Steinmetz, Waring, & Kensinger, 2014). The participants had a maximum of three seconds to respond. The interinterval varied randomly between 4, 4.5, and 5 seconds, with a mean of 4.5 seconds. On DA trials, four words of the same valence were presented successively for 500 ms in random locations around the image. The first word was presented 100 ms after the onset of the image and the other words were presented consecutively with an interstimulus interval of 700 ms. Whenever the presented word started with a vowel (a, e, i, o, u), the participants were instructed to press a button as fast as possible. To ensure that the participants knew which type of trial was going to be presented (FA or DA trial), on DA trials the word ‘words’ appeared under the fixation cross. The images were presented pseudo-randomly in five blocks of 60 images each, with the restriction that an equal amount of images from each category (i.e., positive/low-arousal, positive/high-arousal, negative/low-arousal, negative/high-arousal pictures, and neutral) appeared in each block. For each picture category 30 images were presented during FA trials and 30 images were presented during DA trials and each block comprised 30 FA trials and 30 DA trials. The words were presented randomly with the restriction that an equal amount of neutral, positive, and negative valenced word trials were displayed for each picture category in every block. All stimuli were presented on a monitor with a frame rate of 60 Hz (luminance of ~200 cd/m^2) and were viewed at a visual angle of 7.5° x 7.5°.

(a) Full Attention Trial

(b) Divided Attention Trial

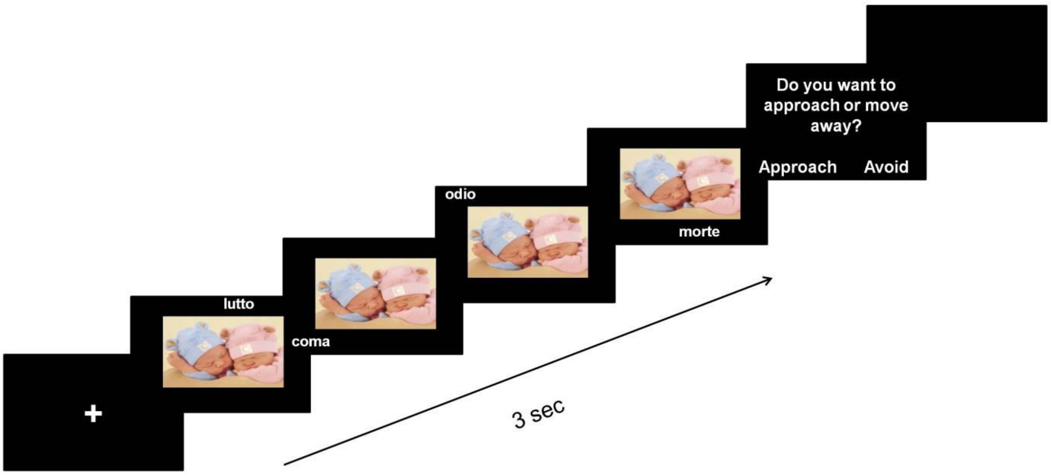


Figure 1. Schematic of the trial structure of the encoding task of (a) a full attention trial and (b) a divided attention trial.

2.4 EEG Recordings and Data Reduction

EEG and electro-ocular (EOG) data were recorded continuously with digitally linked earlobes [(A1 + A2)/2] as reference electrode. EEG signals were recorded from 30 scalp sites (Fp1, Fp2, F7, F3, Fz, F4, F8, FT7, FT8, T3, T4, FC3, FCz, FC4, C3, Cz, C4, CP3, CPz, CP4, TP7, TP8, T5, T6, P3, Pz, P4, O1, Oz, O2), using a pure-tin electrode electrocap. The ground electrode was situated 10 mm anterior to Fz. Electrode impedance was kept below 5 kΩ. The signals were on-line band-limited to 500 Hz, sampled at 1024 Hz, with a gain set at 200, and amplified using a 40-channel NuAmps DC amplifier system (Neuroscan Inc.). In addition, a 50 Hz Notch filter was used. To monitor the vertical EOG, a pair of tin electrodes was placed above and below the center of the right eye, while two electrodes were placed 1 cm lateral to the outer cantus of each eye to monitor the horizontal EOG.

The EEG data was further off-line processed with the Brain Vision Analyzer system (Brain Product). The continuous EEG data was band-pass filtered at 0.10–48 Hz (slope 48 dB/octave). Ocular artifacts were corrected using the Ocular Correction ICA tool implemented in Brain Vision Analyzer. Epochs lasting from 300 ms before image onset until 3000 ms after image onset were extracted for each stimulus. Epochs that contained artifacts exceeding ±75 μV were rejected and artifact-contaminated individual channels were recovered with a statistically weighted interpolation. The EEG was averaged across trials for each trial type and affective condition and then baseline corrected. Based on visual inspection of the difference waveforms, mean amplitudes of the EPN were computed in the time window from 220 ms to 320 ms and of the LPP in the time window from 400 ms to700 ms.

2.5 Procedure

Before the experiment started, the participants read and signed the informed consent. Next, the EEG electrodes were attached and participants were seated in a sound-attenuated and electrically shielded room where the recordings took place. Speed and accuracy in responding was stressed. With regard to the directed attention trials, participants were instructed to focus on the words rather than on the image and the associated approach/avoidance question. After the completion of the task, the participants compiled several personality questionnaires.

2.6 Data Analysis

For the analyses, mean amplitudes of the EPN were averaged over temporal-occipital sites (T5, O1, Oz, O2, T6) and over centro-parietal sites (CP3, CPz, CP4, P3, Pz, P4) for the LPP. ERP data of the EPN and LPP were analyzed separately using an 2 x 5 ANOVA for repeated measures with Condition (FA, DA) and Emotion (positive/low-arousal, positive/high-arousal, negative/low-arousal, negative/high-arousal, and neutral images) as within-subject factors. An additional ANOVA for repeated measures was performed with Word Valence (neutral, negative, positive) as within-subject factor to examine modulatory influences of word valence on the EPN and LPP associated with the processing of the image. When the assumption of sphericity was violated, degrees of freedom were corrected using Huynh-Feldt adjustments to prevent the risk of type 1 errors.

Zero-order correlations were performed to evaluate the relation of BIS, BAS, and its four components (RI, GDP, RR, Imp) with the emotion modulation of the EPN at temporal-occipital sites (T5, O1, Oz, O2, T6) and the LPP at centro-parietal sites (CP3, CPz, CP4, P3, Pz, P4), respectively. The significance of the correlations was assessed through the use of the bias-corrected bootstrap method (5000 samples), which is an effective method in controlling for type 1 errors associated with multiple comparisons (Efron, 1982).

3. Results

3.1 Manipulation Check

In order to ensure that the divided attention trials captured the attentional resources, the reactions time (RT) data in response to the approach/avoidance question was collapsed across responses (approach, avoid) and then submitted to a 2 x 5 ANOVA for repeated measures with Condition (FA, DA) and Emotion (positive/low-arousal, positive/high-arousal, negative/low-arousal, negative/high-arousal, and neutral images) as within-subject factors. An additional three participants were excluded from the analyses of the RT data due to not complying with task instructions, leaving 97 participants for the analysis of the RT data. RTs in response to the approach/avoidance questions were significantly prolonged after DA trials ($M = 958$ ms, $SD = 308$ ms) relative to FA trials ($M = 761$ ms, $SD = 241$ ms), main effect for Condition: $F(1,96) = 106.92$, $p < .0001$, $\eta^2_p = .53$, indicating that the DA trials represented a cognitive demanding task condition. The ANOVA further yielded a significant main effect for Emotion, $F(4,384) = 8.58$, $p < .0001$, $\eta^2_p = .08$, that differed between task conditions, Emotion x Condition: $F(2.61,250.99) = 3.32$, $p = .026$, $\eta^2_p = .03$. While RTs were similar after the presentation of neutral and emotional images during FA trials, all ps $> .05$, RTs were enhanced after the presentation of neutral images compared to all other affective categories, all ps $< .0001$. During FA and DA trials, negative/high-arousal images were associated with shorter RTs relative to negative/low-arousal images, all *p*s < .0001.No other effects were observed, all *p*s > .05.

3.2 Personality Measures

Table 1 reports the Pearson correlation coefficients among the personality scales of the RST-PQ (Corr & Cooper, 2016).

Table 1. *Pearson correlation coefficients for the scales of the RST-PQ (N = 100).*

	1	2	3	4	5	6	7
BIS	1						
FFFS	.36†	1					
BAS-tot	.03	.15	1				
BAS-RI	-.11	-.04	.81†	1			
BAS-RR	.05	.29*	.84†	.56†	1		
BAS-GDP	-.06	.17	.71†	.54†	.48†	1	
BAS-Imp	.20	.00	.67†	.38†	.43†	.19	1

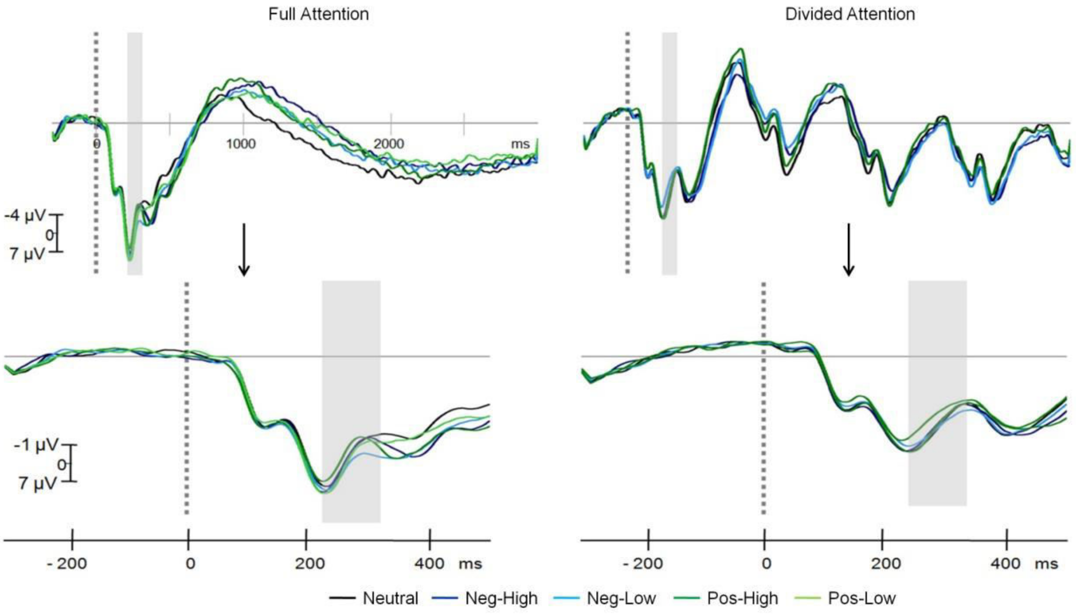
Note: * $p < .005$, † $p < .0001$.

3.3 Event-Related Potentials

3.3.1 Early Posterior Negativity (EPN)

Overall effects. Figure 2 shows the ERPs at temporal-occipital sites comparing the EPN across experimental and affective conditions. The ANOVA yielded a significant main effect for Condition, $F(1,99) = 42.28$, $p < .0001$, $\eta^2_p = .30$, reflecting reduced EPNs during DA trials relative to FA trials. The analysis further demonstrated a main effect for Emotion, $F(4,396) = 6.36$, $p = .013$, $\eta^2_p = .06$, and a significant two-way interaction between Emotion and Condition, $F(4,396) = 2.75$, $p = .028$, $\eta^2_p = .03$. During FA trials, neutral images elicited greater EPNs compared to negative/low-arousal images, $t(99) = -3.35$, $p = .001$. A tendency was observed for greater EPNs in response to negative/high-arousal images relative to negative/low-arousal images, *t*(99) = -2.34, *p* = .021 (n.s. after Boferroni correction), and for positive/high-arousal images relative to positive /low-arousal images *t*(99) = -2.22, *p* = .029 (n.s. after Boferroni correction). No other differences were observed, all p*s* > .05. During DA trials, positive/high-arousal images elicited greater EPNs than neutral images, *t*(99) = -4.32, *p* < .0001. Further, EPNs were enhanced for positive/high-arousal images relative to positive /low-arousal images *t*(99) = -3.59, *p* = .001. Negative/high-arousal images elicited reduced EPNs compared to positive/high-arousal images, *t*(99) = 2.72, *p* = .008. No other effects were detected, all p*s* > .05.

(a) ERP waveforms at temporal-occipital sites



(b) Difference maps showing the early posterior negativity (220-320 ms)

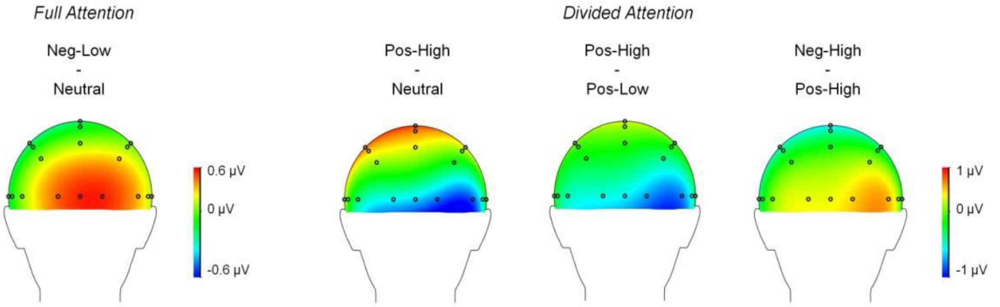


Figure 2. (a) ERP waveforms averaged over temporal-occipital sites (T5, O1, Oz, O2, T6) across affective categories in the two experimental conditions. The upper panel shows the pooled ERP waveforms across the entire epoch, while the epochs of the ERPs shown in the lower panel are shortened to allow for a better illustration of the experimental effects of the EPN. The shaded area indicates the time interval used for the analysis of the EPN (220 - 320 ms). (b) Difference scalp maps showing the EPN (220 - 320 ms) illustrating the experimental effects. Note: Neg-High = negative/high-arousal images, Neg-Low = negative/low-arousal images, Pos-High = positive/high-arousal images, Pos-Low = positive/low-arousal images.

Personality and differential performance. The results of the correlational analyses demonstrated that the influence of individual differences was limited to the FFFS with regard to the EPN at T5 associated with the presentation low and high-arousal negative images presented during FA and DA trials. No other effects were observed, all *p*s > .05 (range of *r* coefficients for the FA condition: -0.15, 0.16; range of *r* coefficients for the DA condition: -0.10, 0.19). Table 2 shows the relevant zero-order correlation coefficients, along with their 95% associated bootstrapped confidence intervals. In Figure 3 a median split was used to plot the relationship between FFFS and EPNs related to the presentation of low and high-arousal negative images presented during FA and DA trials. It can be seen that low-FFFS participants demonstrated enhanced EPNs in response to low and high-arousal negative images presented during DA trials compared to high-FFFS participants. Negative/high-arousal images, but not negative/low-arousal images, presented during FA trials elicited enhanced EPNs in low-FFFS relative to high-FFFS participants.

Table 2. *Zero-order correlations, along with their 95% associated bootstrapped confidence intervals, between the RST-PQ scales and EPNs (220 - 320 ms) at T5 for low and high-arousal negative images presented during full attention and divided attention trials.*

	Full Attention		Divided Attention	
Measure	Neg-High	Neg-Low	Neg-High	Neg-Low
BIS	-0.01 (-0.19, 0.18)	-0.01 (-0.22, 0.19)	0.00 (-0.18, 0.18)	0.10 (-0.09, 0.27)
FFFS	0.21* (0.01, 0.38)	0.10 (-0.11, 0.32)	0.20* (0.01, 0.39)	0.24* (0.03, 0.43)
BAS-tot	-0.03 (-0.22, 0.15)	-0.09 (-0.29, 0.11)	-0.00 (-0.19, 0.19)	-0.06 (-0.25, 0.14)
BAS-RI	0.00 (-0.18, 0.18)	-0.07 (-0.26, 0.13)	-0.02 (-0.20, 0.17)	-0.05 (-0.25, 0.14)
BAS-RR	-0.04 (-0.22, 0.16)	-0.10 (-0.29, 0.11)	-0.05 (-0.24, 0.15)	-0.08 (-0.26, 0.12)
BAS-GDP	-0.01 (-0.17, 0.16)	-0.06 (-0.22, 0.11)	0.06 (-0.13, 0.25)	0.05 (-0.14, 0.23)
BAS-Imp	-0.05 (-0.27, 0.16)	-0.06 (-0.27, 0.15)	0.02 (-0.19, 0.22)	-0.08 (-0.28, 0.12)

Note: * $p < .05$. Neg-High = negative/high-arousal images, Neg-Low = negative/low-arousal images.

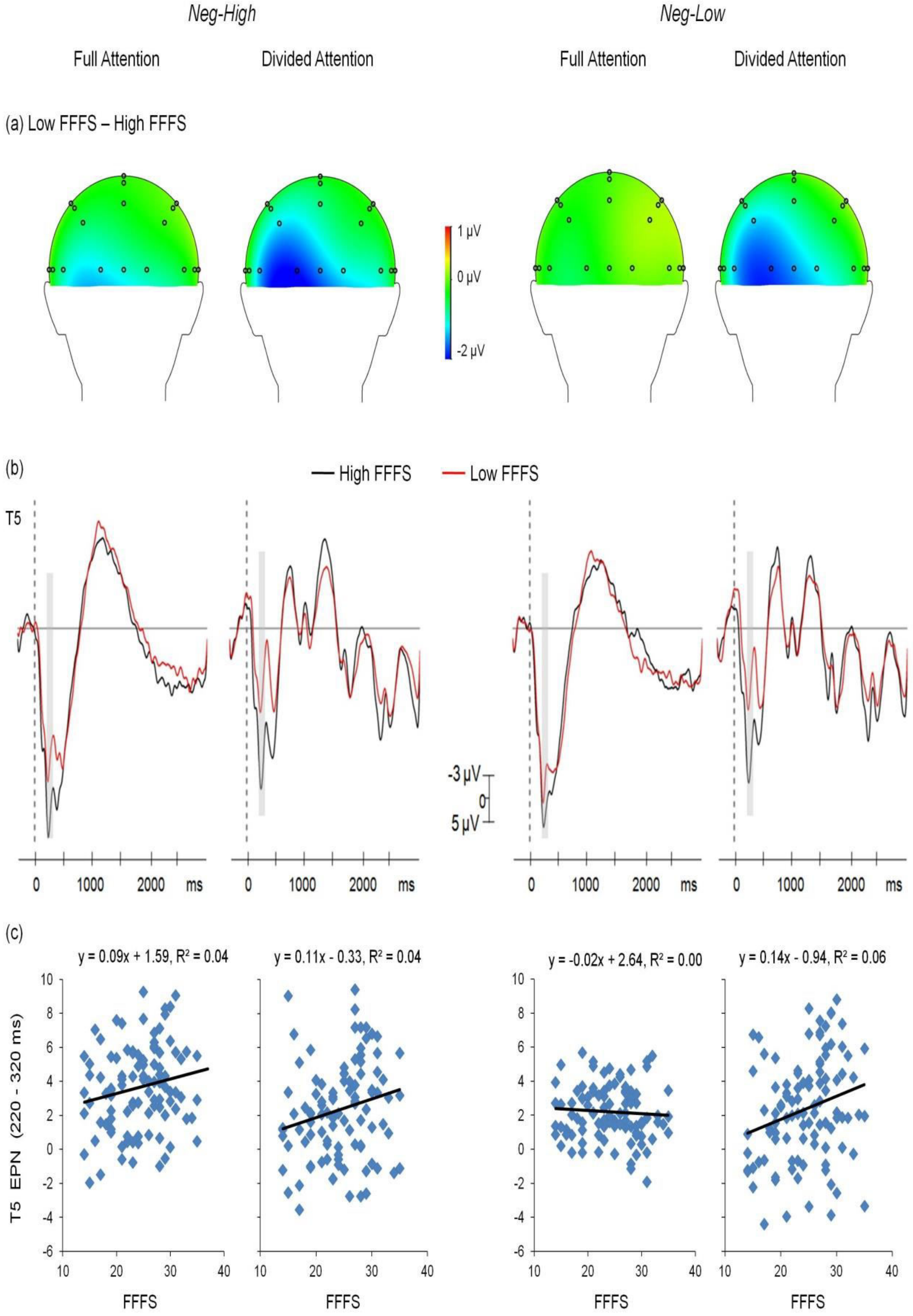
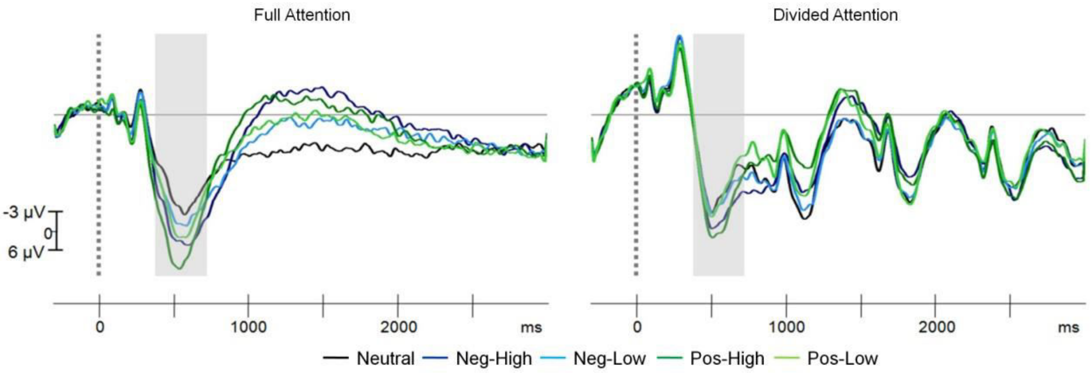


Figure 3. (a) Difference maps, (b) ERP waveforms at T5, and (c) scatterplots comparing high and low FFFS participants with regard to the EPNs (220 - 320 ms) elicited by high and low-arousal negative images presented during full attention and divided attention trials. The shaded area indicates the time interval used for the analysis of the EPN.

3.3.2 Late Positive Potential (LPP)

(a) ERP waveforms at centro-parietal sites



(b) Difference maps showing the late positive potential (400 – 700 ms)

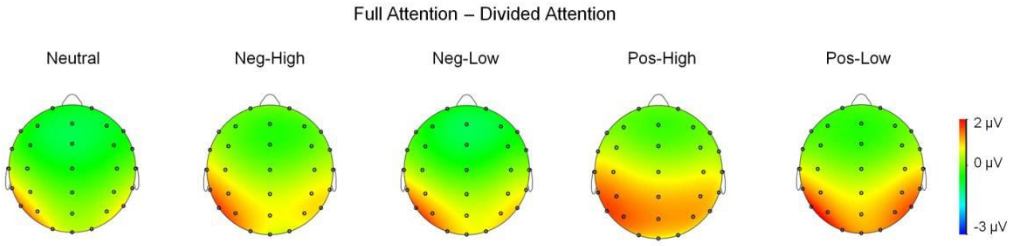


Figure 4. (a) ERP waveforms averaged over centro-parietal sites (CP3, CPz, CP4, P3, Pz, P4) across affective categories in the two experimental conditions. The shaded area indicates the time interval used for the analysis of the LPP (400 - 700 ms). (b) Difference scalp maps of the LPP (400 - 700 ms) comparing full and divided attention trials for each affective condition. Note: Neg-High = negative/high-arousal images, Neg-Low = negative/low-arousal images, Pos-High = positive/high-arousal images, Pos-Low = positive/low-arousal images.

Overall effects. Figure 4 shows the ERPs at centro-parietal sites comparing the LPP across experimental and affective conditions. The results of the ANOVA indicated that the LPP amplitude was larger during FA trials than during DA trials, main effect for Condition, $F(1,99) = 19.62$, $p < .0001$, $\eta^2_p = .17$. The analysis further revealed a main effect for Emotion, $F(4,396) = 32.22$, $p < .0001$, $\eta^2_p = .25$, and a significant two-way interaction between Emotion and Condition, $F(4,396) = 4.20$, $p = .002$, $\eta^2_p = .04$. During FA trials, emotional images elicited greater LPP amplitudes than neutral images, all p*s* < .0001. The LPP amplitude was larger following high-arousal emotional images compared to low-arousal emotional images, all p*s* < .0001. Positive/high-arousal images elicited greater LPP amplitudes than negative/high-arousal images, $t(99) = 2.70$, $p = .008$, while no differences were observed between low-arousal negative and positive images, $t(99) = -.99$, $p > .05$. During DA trials, the differences between neutral and low-arousal emotional images (neutral vs. negative/low-arousal: $t(99) = -.96$, $p > .05$; neutral vs. positive/low-arousal: $t(99) = -.64$, $p > .05$) and between high-arousal negative and positive images, $t(99) = .58$, $p > .05$, were no longer significant. In addition, emotional images (all p*s* < .005), but not neutral images ($t(99) = .96$, $p > .05$), were associated with greater LPP amplitudes during FA trials relative to DA trials.

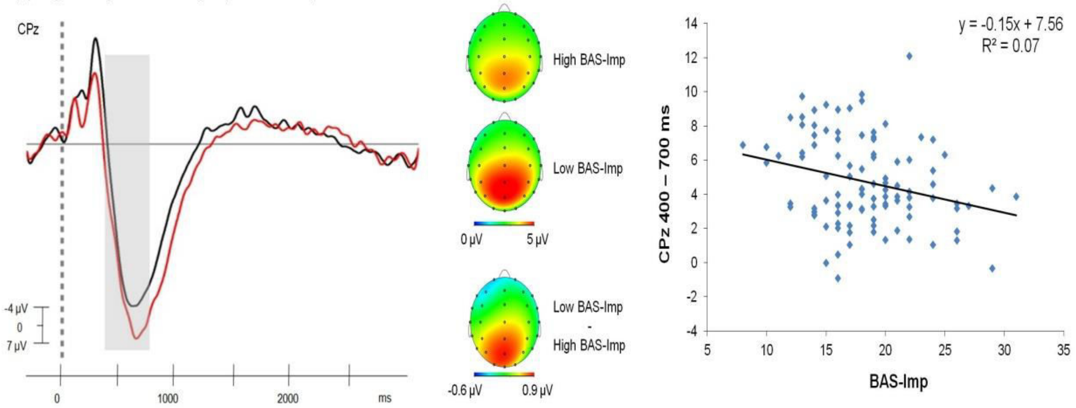
Personality and differential performance. The results of the correlational analyses demonstrated that the influence of individual differences was restricted to BAS-Imp with regard to the LPP amplitude elicited by negative/high-arousal images during FA trials and by low-arousal negative and positive images during DA trials. Further, BAS-RI correlated positively with the LPP amplitudes elicited by negative/low-arousal images during FA trials. No other effects were observed, all *p*s > .05 (range of *r* coefficients for FA trials: -0.18, 0.13; range of *r* coefficients for DA trials: -0.19, 0.11). The relevant zero-order correlation coefficients, along with their 95% associated bootstrapped confidence intervals, are reported in Table 3. The effects were most prominent CPz. Regarding negative/high-arousal images presented during FA trials, additional significant differences were observed for BAS-Imp at CP3 ($r = -.20$, $p = .047$; CI 95% = -.37, -.02), at Pz ($r = -.25$, $p = .013$; CI 95% = -.41, -.07), and at P3 ($r = -.20$, $p = .044$; CI 95% = -.38, -.01). Negative/low-arousal images presented during FA trials demonstrated additional significant differences for BAS-RI at Pz ($r = .24$, $p = .015$; CI 95% = .07, .41) and at P3 ($r = .21$, $p = .039$; CI 95% = .02, .38). In addition, for positive/low-arousal images presented during DA trials significant differences for BAS-Imp were observed at CP4, $r = -.21$, $p = .040$; CI 95% = -.38, -.02. In Figure 5 a median split was used to illustrate the negative relationship between BAS-Imp and LPP amplitudes elicited by negative/high-arousal images during FA trials and by low-arousal negative and positive images during DA trials. Figure 6 shows the positive relationship between BAS-RI and LPP amplitudes elicited by negative/low-arousal images during FA trials.

Table 3. *Zero-order correlations, along with their 95% associated bootstrapped confidence intervals, between the RST-PQ scales and LPP amplitudes (400 - 700 ms) at CPz for high-arousal negative images presented during full attention trials and for low-arousal positive and negative images presented during divided attention trials.*

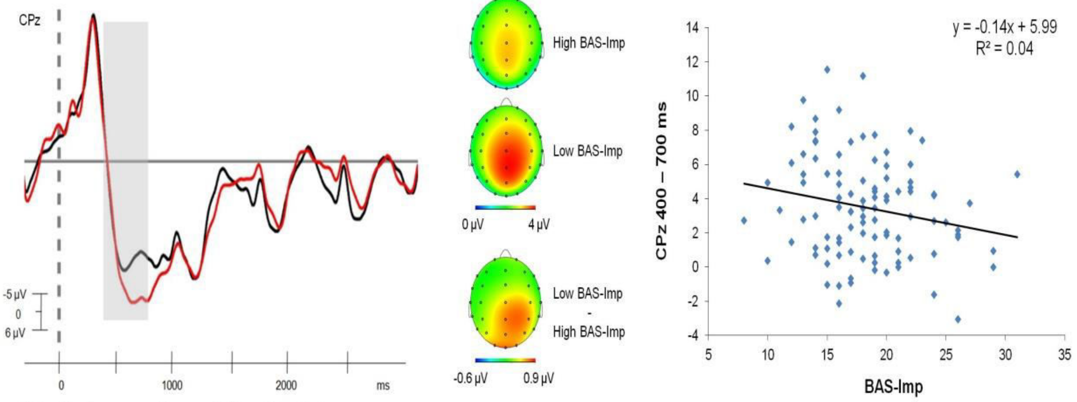
	Full Attention		Divided Attention	
Measure	Neg-High	Neg-Low	Neg-Low	Pos-Low
BIS	0.05 (-0.12, 0.22)	-0.08 (-0.27, 0.13)	0.09 (-0.14, 0.30)	0.05 (-0.13, 0.24)
FFFS	0.05 (-0.14, 0.25)	-0.06 (-0.24, 0.13)	0.05 (-0.13, 0.22)	0.06 (-0.13, 0.24)
BAS-tot	-0.15 (-0.33, 0.05)	0.02 (-0.17, 0.22)	-0.07 (-0.25, 0.12)	-0.20 (-0.36, 0.02)
BAS-RI	0.06 (-0.12, 0.26)	0.21* (0.03, 0.38)	0.07 (-0.09, 0.23)	-0.08 (-0.25, 0.10)
BAS-RR	-0.10 (-0.28, 0.09)	0.00 (-0.19, 0.20)	-0.04 (-0.23, 0.15)	-0.17 (-0.35, 0.01)
BAS-GDP	-0.14 (-0.34, 0.07)	-0.02 (-0.23, 0.18)	-0.02 (-0.21, 0.18)	-0.14 (-0.32, 0.05)
BAS-Imp	-0.26† (-0.43, -0.09)	-0.13 (-0.30, 0.05)	-0.20* (-0.37, -0.02)	-0.20* (-0.37, 0.02)

Note: * $p < .05$, † $p < .01$. Neg-High = negative/high-arousal images, Neg-Low = negative/low-arousal images, Pos-Low = positive/low-arousal images.

(a) Negative/high-arousal images (Full Attention)



(b) Negative/low-arousal images (Divided Attention)



(c) Positive/low-arousal images (Divided Attention)

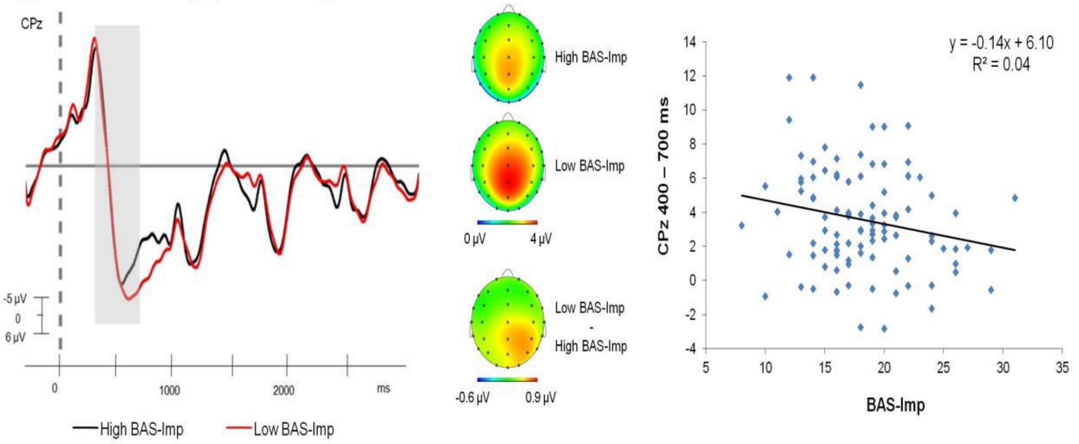
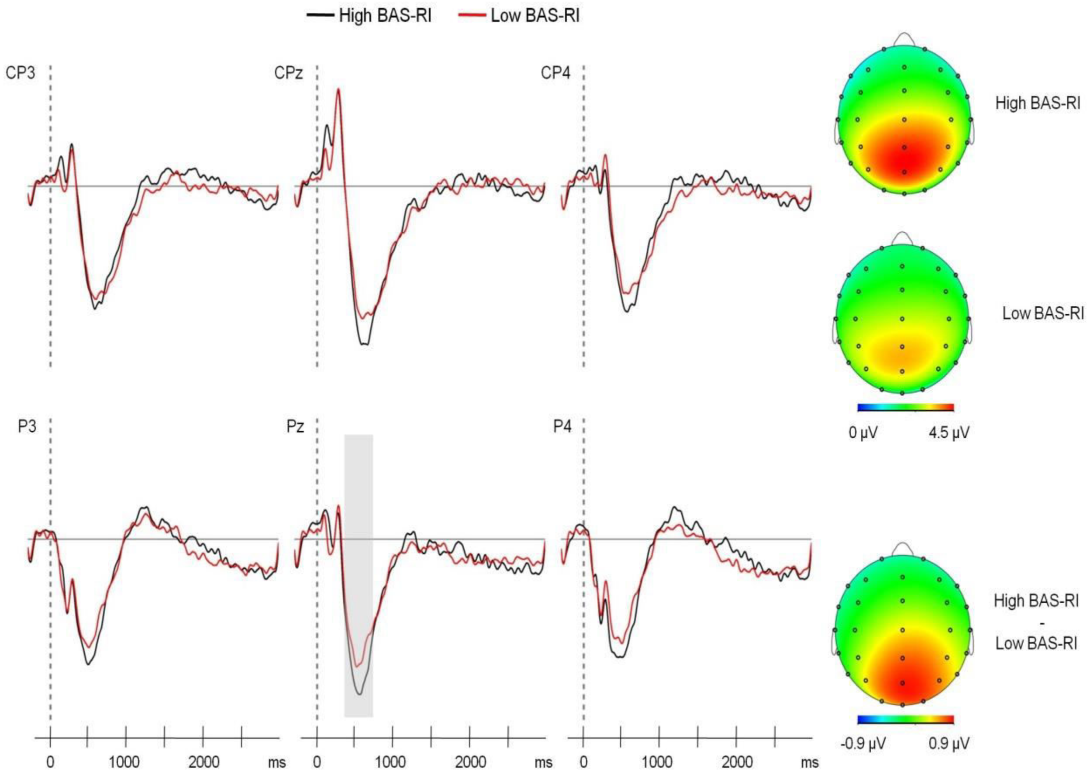


Figure 5. ERP waveforms, scalp distribution and difference maps, and scatterplots illustrating the modulatory influence of BAS-Imp on the late positive potential (400 - 700 ms) associated with (a) negative/high-arousal images presented during full attention trials, (b) negative/low-arousal images presented during divided attention trials, and (c) positive/low-arousal images presented during divided attention trials. The shaded area indicates the time interval used for the analysis of the late positive potential.

(a) ERP waveforms elicited by negative/low-arousal images during full attention trials



(b) Scatterplots showing the relationship between BAS-RI and LPP amplitudes elicited by negative/low-arousal images

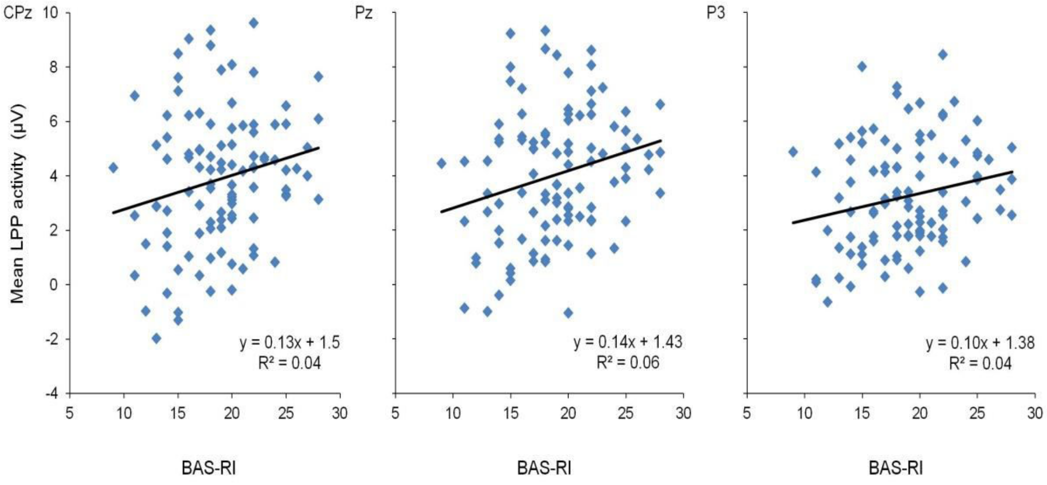
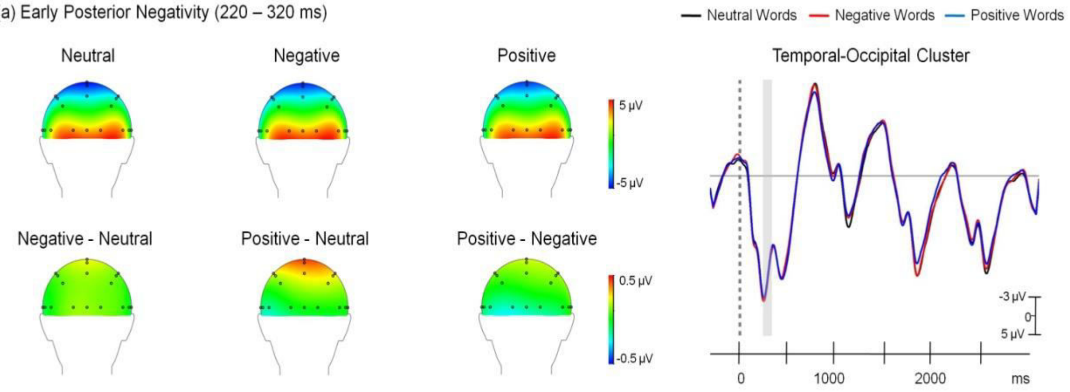


Figure 6. (a) ERP waveforms at centro-parietal sites and scalp distribution and difference maps of the late positive potential (LPP, 400 - 700 ms), respectively, comparing high and low BAS-RI participants in their LPP amplitudes by negative/low-arousal images presented during full attention trials. (b) Scatterplots at significant centro-parietal electrode sites illustrating the positive correlations between BAS-RI and LPP amplitudes elicited by negative/low-arousal images presented during full attention trials. The shaded area indicates the time interval used for the analysis of the LPP.

3.3.3 Influence of word valence on the EPN and LPP

Overall effects. The ANOVA demonstrated a significant main effect for Word Valence with regard to the LPP, $F(2,198) = 4.08$, $p = .018$, $\eta^2_p = .04$, but not for the EPN, $F(2,198) < 1$. Figure 7 illustrates the word valence effects for the EPN and LPP. Post-hoc tests revealed that images presented concurrently with negative words elicited reduced LPP amplitudes compared to images that were presented with positive words, $t(99) = -2.69$, $p = .008$. Images presented together with positive words tended to elicit greater LPP amplitudes than images presented together with neutral words, $t(99) = 1.94$, $p = .05$, while images presented concurrently with neutral and negative words showed no differences in LPP amplitudes, $t(99) < 1$.

(a) Early Posterior Negativity (220 – 320 ms)



(b) Late Positive Potential (400 – 700 ms)

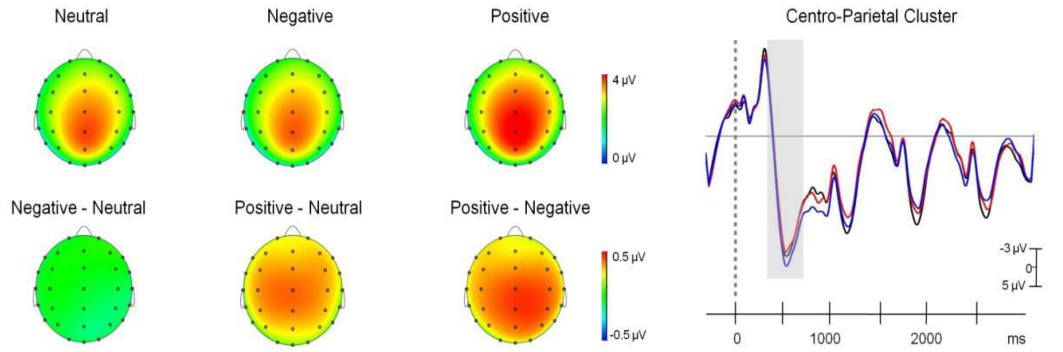


Figure 7. Scalp distribution, difference maps, and pooled ERP waveforms illustrating the modulatory influence of word valence on (a) the early posterior negativity (EPN; 220 - 320 ms) and (b) the late positive potential (LPP; 400 - 700 ms) associated with affective image processing. The shaded area indicates the time interval used for the analysis of the EPN and LPP.

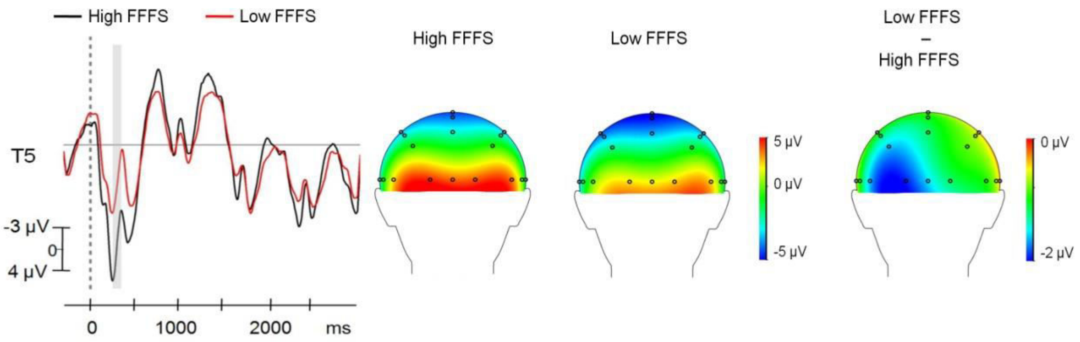
Personality and differential performance. The results of the correlational analyses demonstrated that the influence of individual differences was limited to the FFFS with regard to the EPN at T5 associated with the concurrent presentation of negative words and to BAS-Imp with regard to the LPP at CP4 (and at CPz, $r = -.20$, $p = .049$, CI 95% = -.38, -.01) associated with the concurrent presentation of positive words. No other effects were observed, all *p*s > .05 (range of *r* coefficients for the EPN: -0.12, 0.17; range of *r* coefficients for LPP: -0.18, 0.16). Table 4 presents the pertinent zero-order correlation coefficients, along with their 95% associated bootstrapped confidence intervals. In Figure 8 median splits were used to plot the enhanced EPNs in low-FFFS participants relative to high-FFFS participants in response to images presented with negative words and the greater LPP amplitudes in low BAS-Imp participants relative to high BAS-Imp participants in response to images presented with positive words.

Table 4. *Zero-order correlations, along with their 95% associated bootstrapped confidence intervals, between the RST-PQ scales and EPN and LPP amplitudes for images presented with negative and positive words.*

Measure	T5 EPN Negative Words	CP4 LPP Positive Words
BIS	0.09 (-0.10, 0.26)	0.16 (-0.03, 0.34)
FFFS	0.23 (0.04, 0.42)*	0.11 (-0.07, 0.28)
BAS-tot	-0.05 (-0.23, 0.14)	-0.16 (-0.34, 0.03)
BAS-RI	-0.07 (-0.26, 0.12)	-0.04 (-0.21, 0.14)
BAS-RR	-0.07 (-0.25, 0.11)	-0.11 (-0.30, 0.09)
BAS-GDP	0.01 (-0.17, 0.18)	-0.12 (-0.29, 0.05)
BAS-Imp	-0.00 (-0.19, 0.20)	-0.21 (-0.39, -0.01)*

Note: * $p < .05$.

(a) Early Posterior Negativity (220 – 320 ms): Negative Distractor Words



(b) Late Positive Potential (400 – 700 ms): Positive Distractor Words

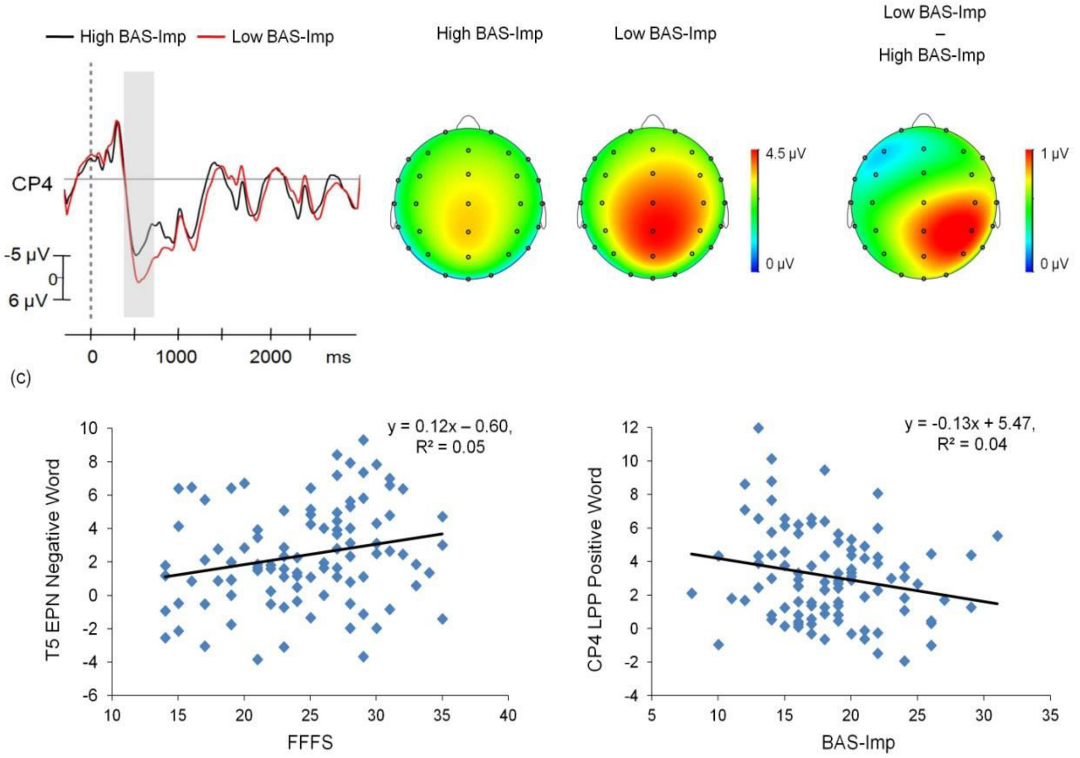


Figure 8. ERP waveforms, scalp distribution, and difference maps illustrating the modulatory influence of (a) the FFFS on the early posterior negativity (EPN; 220 - 320 ms) for images presented with negative words and (b) BAS-Imp on the late positive potential (LPP; 400 - 700 ms) associated with images presented with positive words. (c) Scatterplots showing the relationship between FFFS and the EPN at T5 for images presented with negative words (left) and between BAS-Imp and LPP amplitudes at CP4 for images presented with positive words. The shaded area indicates the time interval used for the analysis of the EPN and LPP.

4. Discussion

The present study aimed to investigate the relative contribution of valence and arousal on exogenous attention to emotional stimuli, as indexed by the EPN and LPP and whether exogenous attention to emotional stimuli is differentially influenced by underlying differences in the RST systems (i.e., BAS and its facets, FFFS and BIS). The results show that exogenous attention is driven by the combined influence of valence and arousal properties of the stimulus with regard to the EPN, while it is influenced by the arousal value regarding the LPP. More importantly, interference by negative images and attention to negative target words was related to the FFFS. Interference by negative and positive/low-arousal images and attention to positive target words were related to the impulsivity facet of the BAS.

As expected, full attention trials elicited stronger EPNs than directed attention trials. The emotion modulation of the EPN at temporal-occipital brain regions during directed attention trials was evident only for positive/high-arousal images. This observation is in line with previous reports demonstrating increased EPNs for positive/high-arousal images relative to low-arousal positive and high-arousal negative images, also when attention was limited (Schupp et al., 2008; Wiens & Syrjänen, 2013). It should be noted that during full attention trials, modulatory effects of emotion on the EPN were obtained only for negative/low-arousal images, indicating reduced selective attention for negative/low-arousal images relative to neutral images. This result is in contrast to expectations and previous research showing enhanced EPNs for emotional relative to neutral stimuli (for reviews see Olofsson et al., 2008; Schupp et al., 2006). Word valence did not differentially affect the influence of interference on EPN strength in relation to the unattended distractor image, which suggests that the valence of the target stimulus does not differentially influence early stages of selective distractor processing.

Regarding the LPP, full attention trials elicited greater LPP amplitudes than directed attention trials, except for neutral images. Directed attention abolished the emotion modulation effects for the LPP, but only for low-arousal emotional images. In contrast to previous findings that reported no emotion modulation effects for the LPP for high-arousal emotional stimuli when attention was directed away from the emotional distractor (De Cesarei et al., 2009; Eimer et al., 2003; MacNamara & Hajcak, 2009, 2010; Nordström & Wiens, 2012; Wiens et al., 2012; Wiens & Syrjänen, 2013), in the current study, high-arousal images continued to elicit greater LPP amplitudes over centro-parietal brain regions than neutral and low-arousal emotional images, even though the LPP amplitudes were reduced. Still, the current results are in line with other studies showing reduced but preserved emotion modulation effects of the LPP, even when attention was limited (Wangelin et al., 2011; Hajcak et al., 2007; Sand & Wiens, 2011; Wiens et al., 2011). Further, the results of the current study are in line with prior research showing that emotional distractor stimuli elicit greater LPP amplitudes than neutral distractor stimuli (Schönwald & Müller, 2014), even though positive distractor images no longer elicited increased LPP amplitudes compared to negative distractor images (Wangelin et al., 2011). In contrast, low-arousal emotional images elicited similar LPP amplitudes during full attention and directed attention trials. Word valence of the target stimulus modulated the interference by the distractor image. Positive words were associated with greater interference by the distractor image (i.e. increased LPP amplitudes) than negative (and neutral) words, while no differences in LPP amplitudes were observed for images presented with neutral and negative words. Since positive emotions and stimuli have been related to a broadening of attentional breadth (e.g., Fenske & Eastwoord, 2003; Fredrickson, 2004, 2005), the result may reflect an increase in attentional breadth due to the positive valence of the word, which resulted in enhanced interference by the distractor images. The lack of LPP differences between images that were presented with neutral and negative words contradicts the results of previous studies showing that negative target stimuli elicit greater LPP amplitudes than neutral target stimuli (MacNamara & Hajcak, 2009, 2010). It is possible that these differences reflect differences in stimulus material of the target stimuli, as the current study employed words, whereas MacNamara and Hajcak (2009, 2010) used images. Images compared to words have been linked to facilitated semantic processing (Carr, McCauley, Sperber, & Parmelee, 1982) and increased neurophysiological responses and activation of brain regions that are associated with emotion processing (e.g., Hinojosa, Carretié, Valcárcel, Méndez-Bértolo, & Pozo, 2009; Kensinger & Schacter, 2006).

The influence of the RST systems on emotional distratcor and target processing was limited to the FFFS and the impulsivity facet of the BAS. Regarding the FFFS, low and high-arousal negative distractor images elicited greater EPNs at left temporal-occipital brain regions in low-FFFS relative to high-FFFS participants. This observation reflects decreased interference by and hence increased active avoidance of the negative distractor stimulus in high-FFFS individuals (e.g., Gray & McNaughton, 2000; McNaughton & Corr, 2004, 2008). During full attention trials, the influence of FFFS was limited to negative/high-arousal images, indicating that the arousal value modulates the relationship between the FFFS and active avoidance of the aversive stimulus when attention is available. In contrast, when attention is directed towards the target stimulus, active avoidance behavior is elicited by a range of negative stimuli, regardless of arousal level. Moreover, higher FFFS scores were related to reduced interference by the distractor images when attention was focused on negative target words, as indexed by reduced EPNs over left temporal-occipital brain regions associated with distractor images. This finding reflects the increased punishment sensitivity associated with the FFFS (e.g., Gray & McNaughton, 2000), which resulted in increased early attention allocation to the negative target word and thereby limiting distratcor interference. In sum, the findings provide support for a two-dimensional model of defense that separates fear from anxiety (e.g., Gray & McNaughton, 2000; McNaughton & Corr, 2004, 2008) by showing that when stimuli elicit no goal-conflict (i.e. concurrent activation of the BAS and FFFS), they elicit defensive behaviors, such as active avoidance, for instance.

Regarding the impulsivity facet of the BAS, higher impulsivity scores were associated with reduced LPP amplitudes in response to low-arousal positive and negative distracor images. Negative/low-arousal images elicited already impaired LPP amplitudes during full attention trials in high impulsive participants relative to low impulsive participants and this effect remained preserved when attention was directed towards the target words. These findings seem to suggest that lower impulsivity scores are related to increased interference by low-arousal emotional distractor images. The impulsivity scale of the RST-PQ (Corr & Cooper, 2016) is a measure of rash impulsivity, reflecting impulsive behavior (i.e. act without reflection and consideration of consequences) that fulfills a fast or physical grabbing action in response to the biological reinforcer at short temporo-spatial distances (Carver, 2005; Corr, 2008). Assuming that impulsivity is concerned with regulatory control over motivated behavior (Depue & Collins, 1999), our findings may reflect increased regulatory control in high impulsive individuals relative to low impulsive individuals, which prevents interference by emotional distratcors when attention is focused on the target stimulus. Impulsivity did not further modulate attentional influences on the emotion modulation of the LPP by high-arousal emotional images, which suggests that the low-arousing nature of the emotional stimulus protects from interference with the primary task in high impulsive individuals. In concordance, higher impulsivity scores were associated with reduced interference by the distractor images when attention was focused on positive target words, as indexed by reduced

LPP amplitudes over right centro-parietal regions. This finding is likely to reflect the overall increased sensitivity towards positive stimuli associated with reward sensitivity (e.g., Gray, 1970; Gray & McNaughton, 2000) together with the need for rapid action associated with the impulsivity facet of reward sensitivity (Carver, 2005) due to the brief presentation duration of the words. All in all, our findings regarding trait influences on attentional modulation of the emotional effects on the LPP are restricted to the impulsivity facet of the BAS. The lacking findings for reward sensitivity and other BAS facets indicate and support the view that it is important to distinguish between impulsivity and reward components (e.g., Corr & Cooper, 2016; De Pascalis, Fracassao, & Corr, 2017; Smillie, Jackson, & Dalgleish, 2006).

Finally, the reward interest facet of the BAS was positively associated with LPP amplitudes over centro-parietal regions in response to negative/low-arousal images during full attention trials. This observation is in accordance with prior research reporting a positive relationship between BAS and its facets and information processing of negative stimuli (e.g., Balconi, Falbo, & Brambilla, 2009) and it supports the view that approach motivation can be brought forth by negative emotions (i.e. anger) or stimuli (e.g., Harmon-Jones, Harmon-Jones, & Price, 2013). The positive correlation was absent during directed attention trials, indicating that attentional resources were insufficient to attentively process the low-arousal negative stimulus and to consequently elicit BAS-related approach behaviors.

With regard to limitations of the present study, it may be argued that this residual attention to high-arousal emotional distractor images is due to insufficient task difficulty (i.e. reduced perceptual load; e.g., Lavie 2005, 2010) of the visual detection task. Still, the RT data and self-reported level of difficulty in responding to the approach/avoidance question assessed during an exit interview (68 participants reported having (major) difficulties and 32 participants reported no or little difficulties in responding) suggest sufficient task difficulty. Although participants were instructed to focus on the words instead of the image and the associated approach/avoidance question during directed attention trials, it is possible that the residual emotional attention effects with respect to the EPN and LPP are in part due to the result of voluntary attentional resources directed towards the image. Further, it should be noted that the sample was not balanced with regard to gender. We do not think that this limits the generalizability of the results as neural activation to emotional stimuli broadly overlaps between sexes (e.g., for a meta-analysis see

Sergerie, Chochol, & Armony, 2008). However, we cannot exclude the possibility that a more balanced gender sample would have increased the generalizability with regard to the RST systems as gender differences have been noted in BIS and BAS means (e.g., Carver & White, 1994).

In conclusion, attentional biases associated with emotional stimuli occur rather automatic, but only for high-arousal emotional images, whereas emotional attention towards low-arousal emotional images seems to require attentional resources. The results of the current study support the notion to differentiate fear from anxiety and reward components from impulsivity (e.g., Corr & Cooper, 2016; Gray & McNaughton, 2000; McNaughton & Corr, 2004, 2008) and show that underlying differences in emotional reactivity influence early exogenous attentional mechanisms to emotional stimuli. Future research needs to further explore the influence of the arousal dimension in personality trait differences in attentional biases for emotional stimuli, as the current results indicate a different pattern of trait influences for low and high-arousal emotional stimuli in automatic emotional attention.

Chapter 4

Neurophysiological Correlates Underlying the Influence of Divided Attention on the Emotional Memory Enhancement Effect

This chapter is based on: Sommer, K., & De Pascalis, V. (in preparation). Neurophysiological correlates underlying the influence of divided attention on the emotional memory enhancement effect.

Abstract

The current study investigated the influence of full and divided attention and the relative contribution of valence and arousal on the early frontal (300 - 500 ms) and late parietal (500 - 800 ms) ERP old/new effect underlying short-term and long-term recognition memory of neutral and emotional images. Participants either passively viewed the affective images or they performed a concurrent affective task-irrelevant task during image presentation. Incidental recognition memory was assessed either 15 minutes (short-term memory group, STM) or one week (long-term memory group, LTM) after the encoding task. The early frontal ERP old/new effect did not differ between the full and divided attention condition, it was unaffected by the valence and arousal value of the images and time delay (STM vs. LTM). Memory performance and the late parietal old/new effect were reduced in the LTM group relative to the STM group, but the emotional influence on memory performance and parietal old/new effects did not differ between groups. Divided attention at encoding did not further modulate the influence of affective content on recognition memory performance, but electrophysiological results indicate that this is due to different underlying mechanisms. The parietal old/new differences associated with full attention were modulated by the valence value, while the valence and arousal value of affective stimuli influenced the late parietal ERP old/new effects associated with limited attention at encoding. Electrophysiological results suggest that visual attentional processes play a role in the recollection based recognition of positive/high-arousal images, but not of negative images, and this effect mediated the influence of trait differences in recognition performance.

1. Introduction

Emotional events are more likely to be remembered than events neutral events. According to Christianson (1992), two processes underlie this emotional memory enhancement effect, especially for negative events: preattentive processing and poststimulus elaboration. Emotional stimuli are assumed to be processed initially on an automatic, preattentive level that then turns into a controlled level of processing through the allocation of attentional resources (i.e. orienting). Preattentive processing refers to an automatic, fast, and non-conscious process, which is assumed to be independent of processing resources. Poststimulus elaboration refers to maintenance processing associated with the previously viewed emotional stimulus. This process is assumed to require effort, attention, and is dependent on limited processing resources.

Support for this account was obtained by studies using a divided attention paradigm. In the divided attention paradigm attention is manipulated through the concurrent performance of another task-irrelevant neutral task (e.g., arithmetic task, auditory discrimination task). Divided attention during the study phase has been shown to impair memory performance relative to full attention, but the memory benefit for emotional relative to neutral stimuli has been found to be unaffected by the level of attention (full vs. divided) (Kern, Libkuman, Otani, & Holmes, 2005; Steinmetz, Waring, & Kensinger, 2014; Talmi & McGarry, 2012). Other studies found that divided attention during the study phase impairs subsequent memory performance for neutral and positive stimuli, but not for negative stimuli (Maddox, Naveh-Benjamin, Old, & Kilb, 2012; Talmi, Schimmack, Paterson, & Moscovitch, 2007). Assessing the influence of emotional arousal on memory for negative and neutral words, it has further been found that under conditions of divided attention, compared to full attention, the memory benefit for nonarousing negative words is reduced (Clark-Foos & Marsh, 2008) or disappears (Kensinger & Corkin, 2004). The aforementioned studies divided attention by using tasks that did not tap the same sensorial modality as the primary task. That is, they divided attention by using tasks that did not tap the same sensorial modality than the primary task. Studies that divided attention through the use of a task that tapped the visual attentional resources showed that happy distractor faces are recognized better than sad faces in a surprise recognition when perceptual load is low, while under condition of high load the opposite pattern is observed (Srinivasan & Gupta, 2010). Further, under conditions of full and divided attention, recall is better for negative images in all levels of arousal, compared to neutral images, except for negative low-arousal images (Pottage & Schaefer, 2012). Examining mediational effects, studies have shown that the performance on the concurrent task (i.e. worse performance due to increased allocation of attentional resources towards emotional stimuli) mediates the memory benefit for emotional stimuli (Pottage & Schaefer, 2012; Talmi & McGarry, 2012; Talmi et al., 2007). While the aforementioned studies examined the role of preattentive processing in emotional memory, other studies examined the role of poststimulus elaboration processes. With the exception of one study (Libkuman, Stabler, & Otani, 2004), the majority of studies have demonstrated that poststimulus elaboration plays a minor role in the memory benefit for emotional, especially for negative arousing stimuli (Buratto, Pottage, Brown, Morrison, & Schaefer, 2014; Migita, Otani, Libkuman, & Sheffert, 2011; Steinmetz et al., 2014). Few studies have examined the influence of emotional distraction on memory performance for neutral and emotional stimuli. When simultaneously presenting the emotional images (negative or positive) with emotional distractors (neutral or opposite valence of image), no influence of distractor valence on recognition memory for negative items has been found, while recognition accuracy for positive images increases when presented with neutral distractors relative to negative distractors (Ziaei, von Hippel, Henry, & Becker, 2015). However, when the to be remembered material is neutral in valence, neutral and negative arousing distractors presented during a delay impair subsequent (working) memory performance for neutral faces and deactivate brain regions in the dorsolateral prefrontal cortex that are generally associated with working memory (Buchner, Rothermund, Wentura, & Mehl, 2004; Dolcos, Diaz-Grandados, Wang, & McCarthy, 2008; Dolcos & McCarthy, 2006, Iordan & Dolcos, 2017; Zanto, Clapp, Rubens, Karlsson, & Gazzaley, 2016).

The reviewed studies examining the influence of attentional processes in the memory benefit for emotional material are mainly behavioral studies, with the exception of few fMRI studies (Dolcos et al., 2008; Dolcos & McCarthy, 2006; Iordan & Dolcos, 2017). Event-related potentials (ERP) during memory retrieval have been shown to be more positive in response to correctly classified old stimuli than correctly classified new stimuli. Previous research has identified two separate components of this ERP old/new effect: an early frontal old/new effect (300-500 ms) that is hypothesized to reflect familiarity and a late parietal old/new effect (500-800 ms) that is thought to reflect recollection (Friedman & Johnson, 2000; Rugg & Curran, 2007). ERP studies of emotional memory have reported mixed results with regard to the influence of emotional content on the ERP old/new effect. Some studies reported greater old/new effects for emotional relative to neutral stimuli for both the early frontal and late parietal old/new component (Schaefer, Pottage, & Rickart, 2011; Xu, Zhang, Li, & Guo, 2015), while other studies observed increased old/new effects for emotional stimuli for the late parietal old/new component but not for the early frontal old/new component (Johansson, Mecklinger, & Treese, 2004; Maratos, Ellen, & Rugg, 2000; Weymar, Bradley, El-Hinnawi, Lang, 2013; Weymar, Löw, Melzig, & Hamm, 2009), increased old/new effects for emotional stimuli for the early frontal old/new component but not for the late parietal old/new component (Wang, Wu, Gao, Yang, Wang, & Li, 2013), or no differences between emotional and neutral stimuli in the old/new effects (Windmann & Kutas, 2001). Further, the results are inconsistent concerning possible differences between affective categories (positive vs. negative) in the old/new effect: observations range from no differences in the late parietal ERP old/new effect between negative and positive stimuli (Wang et al., 2013; Weymar et al 2009; Xu et al., 2015), to a greater early frontal and/or late parietal ERP old/new effect for negative compared to positive stimuli (Inaba, Nomura, & Ohira, 2005; Johansson et al., 2014; Weymar, Löw , & Hamm, 2011), or an increased early frontal old/new effect for positive relative to negative stimuli (Xu et al., 2015).

It has been suggested that the memory enhancement effect for high-arousal emotional stimuli occurs rather automatic, whereas the memory enhancement effect for low arousing emotional stimuli is assumed to be modulated by controlled and conscious encoding strategies (Kensinger, 2004). Thus, if these controlled encoding processes underlie the memory enhancement effect for low-arousal emotional stimuli, then divided attention at encoding should disrupt the memory enhancement effect for emotional stimuli low in arousal. Studies have shown that when attention is divided during stimulus presentation, negative stimuli high in arousal are associated with increased recall relative to low-arousal negative and neutral stimuli (Kensinger & Corkin, 2004; Pottage & Schaefer, 2012), while no influence of arousal on memory performance has been observed when attention is divided during the interstimulus interval (Libkuman et al., 2004). Little research exists with regard to valence-arousal interactions in the emotional memory enhancement effect. Low-arousal images have been shown to be remembered better than neutral images but less well than medium or high-arousal images (Ochsner, 2000; Schaefer et al., 2011; Steinmetz & Kensinger, 2009; Xu et al., 2015). Some studies reported better memory performance for positive/high-arousal stimuli than negative/high-arousal items, while no differences have been observed for emotional stimuli low in arousal (Gomes, Brainerd, & Stein, 2013; Xu et al., 2015), while another study observed that memory performance is affected by the arousal value but not the valence of the stimulus (Bradley, Greenwald, Petry, & Lang, 1992). Only positive/low-arousal images, but not negative/low-arousal images, have been shown to be associated with similar recognition performance relative to neutral images (Steinmetz & Kensinger, 2009). Other studies failed to find arousal differences in recognition memory performance (Kaestner & Polich, 2011; Van Strien, Langeslag, Strekalova, Gootjes, & Franken, 2009). ERP studies have reported greater early frontal and late parietal ERP old/new effects for high compared to low arousal stimuli (Kaestner & Polich, 2011; Schaefer et al., 2011; Xu et al., 2015), while another study found no influence of arousal level on the ERP old/new effects (Van Strien et al., 2009). Some fMRI studies reported strengthened amygdalar connectivity in response to high-arousal negative images, relative to low-arousal negative images, while for positive images the opposite pattern was observed (Steinmetz, Addis, & Kensinger, 2010; Steinmetz & Kensinger, 2009). Further, for negative images, arousal leads to a more widespread connectivity between other nodes associated with the memory network, while for positive images the effect of arousal is restricted to the amygdala.

Previous research manipulated attention either through a neutral divided-attention paradigm or through the appearance of emotional distractors. Therefore, it remains unclear how divided attention, through the use of a concurrent performance of an emotional task, influences the memory benefit for emotional and neutral stimuli. Further, with the exception of a small number of studies (Weymar et al., 2009, 2011), previous ERP studies on emotional memory have mainly used short retention intervals. Since memory consolidation, the transformation of a newly formed memory trace from a labile state into a more stable state (i.e. long-term memory), is a process that takes several hours (or even longer) to complete (e.g., Dudai, 2004), more studies are needed that assess the memory enhancement effect after longer delays. Some evidence suggests that the emotional memory enhancement effect remains stable over time, especially for negative stimuli (Sharot & Yonelinas, 2008; Wang, 2014; Weymar et al., 2011). ERP studies examining general recognition performance have reported no difference in frontal and parietal old/new effects between recent and remote memories using a 24 hour retention interval (Curran & Friedman, 2004; Jaeger, Johnson, Corona, & Rugg, 2009; Wolk et al., 2006). Using longer retention intervals (one week or four weeks), other studies have reported no influence of time delay on the frontal old/new effect, but a reduced or absent parietal old/new effect for remote relative to recent memories (Roberts, Tsivilis, & Mayes, 2013; Tsivilis et al., 2015). Therefore, the current study investigated the influence of full and divided attention and the relative contribution of valence and arousal on the early frontal and late parietal ERP old/new effect underlying short-term and long-term emotional memory retrieval. Accordingly, we presented our participants with neutral images and emotional images (negative and positive) that were either high or low in arousal. The images were either passively viewed (full attention) or they were surrounded by emotional and neutral words in response to which participants were required to perform a concurrent task (divided attention). An incidental memory recognition task followed either 15 minutes (short-term memory group, STM) or one week (long-term memory group, LTM) after the encoding task. Based on previous findings reviewed in this section, we expected impaired recognition memory under conditions of divided attention, without eliminating the enhanced recognition of emotional relative to neutral images. We expected to replicate previous findings showing that recognition memory is better for emotional than neutral images and that this effect is greater for emotional images high in arousal relative to low arousal images. Regarding the ERP old/new effects it was further hypothesized that emotional images are associated with greater ERP old/new effects than neutral images. This effect was expected to be more pronounced for high arousal relative to low arousal emotional images. No differences were expected in the emotional modulation of ERP old/new differences between the conditions of full and divided attention. Since the late parietal old/new effect is thought to reflect recollection (e.g., Rugg & Curran, 2007) and given that divided attention impairs recognition performance, we hypothesized a reduced late parietal old/new effect for images initially presented during the divided attention condition compared to images viewed under full attention. Finally, the LTM group was expected to show impaired recognition performance and a reduced late parietal old/new effect relative to the STM group. No other group differences were expected.

A secondary aim of the present study was to examine the influence of individual differences in the anxiety, fear, and approach systems (e.g., Gray 1970; Gray & McNaughton, 2000) on attentional influences in the emotional memory enhancement effect. The behavioral approach system (BAS) is sensitive to signals of reward and is associated with positive emotions. The fight-flight freeze system (FFFS) is activated by signals of punishment and threat and its activation results in the experience of fear. The behavioral inhibition system (BIS) is sensitive to signals of punishment, nonreward, and novelty, and conflicting stimuli (e.g., due to concurrent activation of the BAS and FFFS), and its activation inhibits ongoing behavior, it increases attention and arousal, and it results in the experience of negative affect. Studies have shown that the BAS is positively associated with memory for positive information, while the BIS is positively associated with memory for negative information (Gomez, Cooper, McOrmond, & Tatlow, 2004; Gomez & Gomez, 2002). It was hypothesized that the FFFS and BIS are associated with memory for negative images, while the BAS and its facets were expected to be associated with memory performance for positive images. Trait-congruency effects in the memory benefit for emotionl stimuli were expected to be unaffected by attentional manipulations. We further examined the hypothesis that the observed relationships between BIS, FFFS, and BAS, with the recognition performance for emotional stimuli are mediated by ERP old/new differences.

2. Method

2.1 Participants

A total of 104 graduate psychology students from the La Sapienza University of Rome participated for course credit. One participant of the long-term memory group was excluded from the analyses due to technical problems during the recordings of the memory task. Another two participants of the long-term memory group were excluded from the analyses as they did not complete the second session of the experiment. Finally, 24 participants were excluded due to poor performance in the memory task, resulting in an insufficient number of epochs for averaging. The final sample consisted of 77 participants (58 females, 19 males) ranging in the age from 21 to 34 years (*M* = 24.36, *SD* = 2.72). Forty-two participants performed the memory task 15 minutes after the encoding task (STM group, 10 males and 32 females) and the other 35 participants performed the memory task one week after the encoding task (LTM group, 9 males and 26 females). The study was approved by the local ethics board. All participants had normal or corrected-to-normal vision and they reported no history of neurological or psychiatric disorders or usage of certain medications and drugs that might interfere with the EEG recordings. Appointments for female participants were scheduled so that the recordings did not overlap with their menstrual period. Before participation each participant provided written informed consent.

2.2 Questionnaires

Reinforcement Sensitivity Theory Personality Questionnaire. The Reinforcement Sensitivity Theory Personality Questionnaire (RST-PQ; Corr & Cooper, 2016) is a newly constructed questionnaire that is based on the revised RST (Gray & McNaughton, 2000). The RST-PQ consists of 73 items (e.g., 'I am very persistent in achieving my goals'). Respondents are asked to indicate how accurately each statement describes them in general. Each item is rated on a 4-point scale, ranging from 1 (not at all) to 4 (highly). The RST-PQ consists of subscales that measure the Fight-Flight-Freeze System (FFFS), the Behavioral Inhibition System (BIS), and four Behavioral Approach System (BAS-tot) factors, which are considered in this study: Reward Interest (RI), Goal-Drive Persistence (GDP), Reward Reactivity (RR), and Impulsivity (Imp).

2.3 Experimental Tasks: Stimuli and Design

Participants performed an encoding task followed by a memory task. The EEG was recorded during both tasks. The stimuli were presented on a computer monitor with a frame rate of 60 Hz (luminance of ~200 cd/m^2, 7.5° of visual angle).

2.3.1 Stimuli

Images. Six hundred images (120 positive/low-arousal images, 120 positive/high-arousal images, 120 negative/low-arousal images, 120 negative/high-arousal images, and 120 neutral images) were selected from the International Affective Picture System (Lang, Bradley, & Cuthbert, 2008) and from the Geneva Affective Picture Database (Dan-Glauser & Scherer, 2011). The images were selected based on rating data obtained from 28 students, using a 9-point Likert scale, ranging from 1 (*negative valence* or *low arousal*) to 9 (*positive valence* or *high* *arousal*). An analysis of variance (ANOVA) on the valence ratings revealed a main effect for valence, $F(4,599) = 2772.13$, $p < .0001$. Post-hoc comparisons indicated differences in valence ratings across emotional categories, all *p*s < .0001, except between low and high-arousal positive images, $p = .38$. Further, the ANOVA on the arousal ratings yielded a main effect of arousal, $F(4,599) = 871.79$, $p < .0001$. Emotional images were rated as more arousing than neutral images, all *p*s < .0001, and high-arousal emotional images were rated as more arousing than low-arousal emotional images, all *p*s < .0001. Negative/high-arousal images were rated more arousing than positive/high-arousal images, $p < .0001$, and negative/low-arousal images were rated more arousing than positive/low-arousal images, $p < .0001$. The images were divided into two sets of 300 images each (60 positive/low-arousal images, 60 positive/high-arousal images, 60 negative/low-arousal images, 60 negative/high-arousal images, and 60 neutral images). One set contained the images presented during the encoding task, while the other set contained the new images presented in the memory task. The order of the sets was counterbalanced across participants. The sets did not differ with regard to valence and arousal ratings across affective categories, all *p*s > .05.

Words. Six hundred words (verbs, adjectives, and nouns) were selected from an Italian dictionary (De Mauro, Mancini, Vedovelli, & Voghera 1993). The words were selected based on affective ratings obtained from 64 students. The ratings were obtained using a 9-point Likert scale, ranging from 1 (*negative valence* or *low arousal*) to 9 (*positive valence* or *high arousal*). The final set consisted of 200 positive ($M = 6.78$, $SD = .48$), 200 negative ($M = 3.07$, $SD = .59$), and 200 neutral words ($M = 5.00$, $SD = .49$), that differed in rated valence, all *p*s < .0001. Each word had a low frequency of use and it consisted of a maximum of three syllables and seven characters. No significant differences in frequency of use were observed between the affective word conditions (i.e. neutral, positive, negative), $p > .05$.

2.3.2 Trial Structure – Encoding Task

As can be seen in Figure 1, full attention (FA) trials started with the presentation of a fixation cross for 500 ms. Next, an in emotional or neutral image was be presented on the screen for three seconds. After the offset of each image, participants were asked to make an approach/avoidance decision (Steinmetz et al.,

2014) in response to the prior image to ensure that they attended to the presented material. The time to respond was limited to three seconds. Then, an intertrial interval followed, randomly varying between 4, 4.5, and 5 seconds with a mean of 4.5 seconds. On divided attention (DA) trials, words were presented in random locations around the image one at a time. Each word remained on the screen for 500 ms. Then a new word was presented in a different location. Participants were instructed to press a button as quickly as possible, when the presented word started with a vowel (a, e, i, o, u). A total of four words of the same valence were presented during the presentation of each image. The first word appeared 100 ms after the onset of the image, after which the other words were presented with an interstimulus interval of 700 ms. To ensure that the participants were aware of the type of trial to be presented (FA or DA trial), on DA trials the fixation cross was accompanied by the word 'words'. The images were presented pseudo-randomly in five blocks of 60 pictures each, with an equal amount of images from each category (i.e., positive/low-arousal, positive/high-arousal, negative/low-arousal, negative/high-arousal pictures, and neutral) occurring in each block. On DA trials, an equal amount of neutral, positive, and negative valenced word trials were presented for each picture category in each block. FA trials DA trials were presented pseudo-randomly, with the restriction that the same number of FA trials and DA trials (i.e. 30) occurred in each block. For each affective category 30 images were presented during FA trials and 30 images were distributed during DA trials.

2.3.3 Trial Structure – Memory Task

Recognition task. The 300 old images shown in the encoding task (60 positive/low-arousal images, 60 positive/high-arousal images, 60 negative/low-arousal images, 60 negative/high-arousal images, and 60 neutral images) were presented together with 300 new images (60 positive/low-arousal images, 60 positive/high-arousal images, 60 negative/low-arousal images, 60 negative/high-arousal images, and 60 neutral images). A 500 ms fixation cross preceded each image presentation. Each image was displayed for three seconds. Following each image presentation, the participants indicated whether they had seen the image before by making yes/no recognition judgments. No time limit was imposed on the recognition judgments. The images were presented in three blocks of 200 images each. Image presentation was pseudo-random, with an equal number of images from each category (i.e., positive/low-arousal, positive/high-arousal, negative/low-arousal, negative/high-arousal pictures, and neutral) and each condition (new, old-FA, old-DA) occurring in each block. A schematic of the trial structure is shown in Figure 2.

(a) Full Attention Trial

(b) Divided Attention Trial

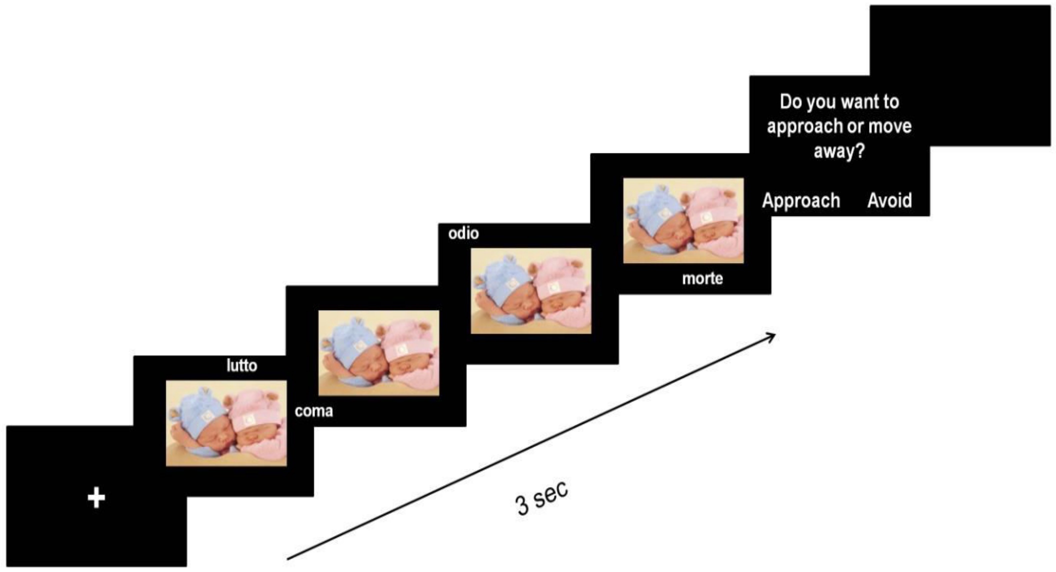


Figure 1. Schematic of the trial structure of the encoding task of a full attention trial (a), and of a divided attention trial (b).

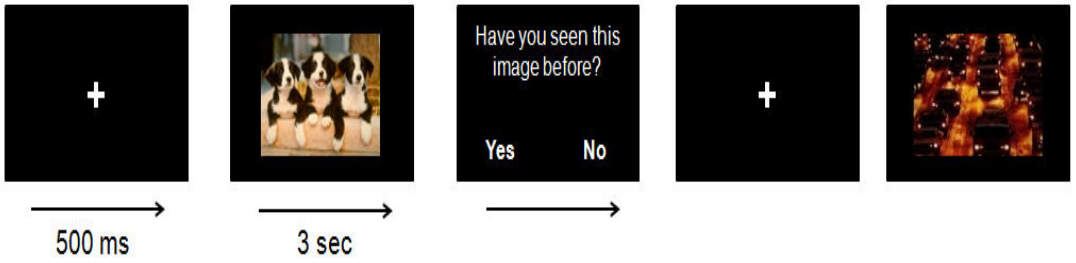


Figure 2. Schematic of the trial structure of the memory recognition task.

2.4 EEG Recordings and Data Reduction

EEG, and electro-ocular (EOG) data were recorded continuously by using a 40-channel NuAmps DC amplifier system (Neuroscan Inc.), with a gain of 200, sampling rate of 1024 Hz, and with signals band-limited to 500 Hz, with a 50 Hz Notch. Scalp impedances for each electrode was lower than 5 kΩ. EEG data was recorded from 30 electrodes (Fp1, Fp2, F7, F3, Fz, F4, F8, FT7, FT8, T3, T4, FC3, FCz, FC4, C3, Cz, C4, CP3, CPz, CP4, TP7, TP8, T5, T6, P3, Pz, P4, O1, Oz, O2), using a pure-tin electrode electrocap, with a ground electrode located 10 mm anterior to Fz. The EEG was referenced to digitally linked earlobes [(A1 + A2)/2]. Standard tin electrodes were used to record the vertical EOG from the supra- and infra-orbital positions of the left eye, and the horizontal EOG from the epicanthus of each eye.

The EEG was further processed with the Brain Vision Analyzer 2.1 system (Brain Product). The EEG was off-line filtered at 0.10–48 Hz (Butterworth zero phase filter with 48 dB/octave). Rejected frontal polar electrodes were interpolated using a statistically weighted interpolation from the full channel set. The Ocular Correction ICA tool, implemented in Brain Vision Analyzer, was used to correct for ocular artifacts. An epoch length of 3300 ms, with a 300 ms pre-stimulus baseline, was used for each stimulus. The EEG was manually checked for artifacts and any trials that contained artifacts exceeding ±75 µV were dropped. The single EEG epochs were then averaged across trials for each affective category and condition and baseline corrected. Only trials with correct responses were included in the ERP averages.

Based on visual inspection of the waveforms, as well as previous studies (e.g., Weymar et al., 2009), mean ERP amplitudes were computed in a 300–500 ms window (frontal old/new effect) and a 500–800 ms time window (parietal old/new effect). Two electrode clusters over fronto-central sites (F3, Fz, F4, FC3, FCz, FC4) and centro-parietal sites (CP3, CPz, CP4, P3, Pz, P4) were selected for further analyses.

2.5 Procedure

Before the experiment started, the participants read and signed the informed consent. Next, the EEG electrodes were attached and participants were seated in a sound-attenuated and electrically shielded room where the recordings took place. Before and after each task, participants filled in the STAI-Y1 and PANAS questionnaire. The encoding task was followed by the memory task either 15 minutes

(STM group, n = 42) or one week (LTM group, n = 35) after the encoding task had been completed. After the encoding task, the participants compiled several questionnaires, which were, if needed, completed after the memory task. The participants were not informed that their memory would be tested subsequently. Speed and accuracy in responding was stressed in all tasks.

2.6 Data Analysis

The discrimination index *Pr* was calculated according to Snodgrass and Corwin (1988). Higher Pr values [p(hit) - p(false alarm)] reflect enhanced discrimination between old and new items. Hit rates, Pr values, and reaction times were analyzed using a 2 x 5 x 2 ANOVA for repeated measures with Condition (old-FA, old-DA), and Emotion (positive/low-arousal, positive/high-arousal, negative/low-arousal, negative/high-arousal, and neutral images) as within-subject factors and Group (STM, LTM) as between subject factor. To assess the influence of word valence on image recognition a 3 x 5 x 2 ANOVA for repeated measures was performed on the hit rates, Pr values, and reaction times with regard to the images presented during DA trials with Word Valence (neutral, positive, negative) and Emotion (positive/low-arousal, positive/high-arousal, negative/low-arousal, negative/high-arousal, and neutral images) as within-subject factors and Group (STM, LTM) as between subject factor. The influence of word valence on recall performance of the words was analyzed using a 3 x 2 ANOVA with word valence (neutral, negative, positive) as within-subject factor and Group (STM, LTM) as between subject factor..

Mean ERP amplitudes were analyzed separately for the early time window (300-500 ms) over frontal sites and for the late time window (500-800 ms) over parietal sites (e.g., Wang et al., 2013; Weymar et al., 2013) using an 3 x 5 x 2 ANOVA for repeated measures with Condition (new, old-FA, old-DA) and Emotion (positive/low-arousal, positive/high-arousal, negative/low-arousal, negative/high-arousal, and neutral images) as within-subject factors and Group (STM, LTM) as between subject factor.

Zero-order correlations were performed to evaluate the relation of the frontal ERP old/new effects, parietal ERP old/new effects and behavioral measures (hits, Pr) with BIS, BAS, and its four components (RI, GDP, RR, Imp). The bias-corrected bootstrap method (5000 samples) was used to assess the significance of the correlations. The bootstrap method is effective in controlling for type 1 errors associated with multiple comparisons (Efron, 1982).

An alpha level of 0.05 was used for all analyses. Bonferroni corrected follow-up comparisons were conducted on significant main and interaction effects that included the factor Emotion. To prevent the risk of type 1 errors, degrees of freedom were adjusted using Huynh-Feldt adjustments, when the assumption of sphericity was violated.

3. Results

3.1 Behavioral Data

Overall Performance. An overview of the memory performance (i.e., proportion of correct responses, discrimination accuracy, and reaction times) is presented in Table 1. The ANOVA performed on the hit rates yielded a main effect for Condition, $F(1,75) = 370.52$, $p < .0001$, $\eta^2_p = .838$, indicating that recognition performance was higher for old images previously presented during FA trials (86%, *SE* = 2%), compared to images presented during DA trials (64%, *SE* = 2%). This effect was not further modulated by the emotional content of the images, Condition x Emotion: $F(3.24,243.30) = 1.35$, $p > .05$, and did not differ between groups, Condition x Group: $F(1,75) = 1.06$, $p > .05$. In general, recognition performance was enhanced in the STM group (85%, *SE* = 2%) relative to the LTM group (63%, *SE* = 3%), $F(1,75) = 53.51$, $p < .0001$, $\eta^2_p = .42$. Hit rates were modulated by the emotional content of the images, irrespective of the condition (FA vs. DA), main effect for Emotion: $F(3.71,278.09) = 18.65$, $p < .0001$, $\eta^2_p = .20$. Follow-up analyses indicated that only positive/low-arousal images were associated with reduced hit rates relative to neutral images, $F(1,75) = 52.32$, $p < .0001$, $\eta^2_p = .41$. Further, hit rates were significantly higher for negative/low-arousal images compared to positive/low-arousal images, $F(1,75) = 33.42$, $p < .0001$, $\eta^2_p = .31$, and positive/high-arousal images were linked to higher hit rates relative to positive/low-arousal images, $F(1,75) = 56.55$, $p < .0001$, $\eta^2_p = .43$. Hit rates did not differ between emotional images high in arousal and between negative images high and low in arousal, all F*s* < 1. The higher order interaction Condition x Emotion x Group failed to reach significance, $F(4,300) = 1.30$, p > .05. The results of the ANOVA regarding the influence of word valence on recognition performance for images previously presented during DA trials failed to reveal significant effects, all p*s* > .05. Separate

ANOVAs for each emotional category yielded a significant influence of word valence on Hit rates for neutral images, $F(2,150) = 5.05$, $p = .008$, $\eta^2_p = .06$, indicating greater hit rates for neutral images paired with negative words relative to positive, $F(1,75) = 6.93$, $p = .010$, $\eta^2_p = .09$, and neutral words, $F(1,75) = 8.34$, $p = .005$, $\eta^2_p = .10$, while Hit rates for neutral images paired with neutral and positive words did not differ, $F(1,75) < 1$. Hit rates for emotional images were not affected by word valence during DA trials, all p*s* > .05. This effect is plotted in Figure 3.

The ANOVA performed on the discrimination accuracy scores yielded the same results as the ANOVA performed on the Hit scores, except for the differences in discrimination accuracy between neutral and emotional images. That is, the old/new discrimination was better for neutral relative to emotional images, all p*s* < .01.

Table 1. *Means for the proportions of correct responses (Hit) and the discrimination index for old images that were initially presented under conditions of full and divided attention.*

	Neutral	Neg-High	Neg-Low	Pos-High	Pos-Low
(1) Full Attention					
Hit	0.89 (0.02)	0.88 (0.02)	0.86 (0.02)	0.88 (0.02)	0.80 (0.03)
Pr	0.84 (0.02)	0.83 (0.02)	0.79 (0.02)	0.82 (0.03)	0.73 (0.03)
(2) Divided Attention					
Hit	0.68 (0.02)	0.63 (0.02)	0.65 (0.02)	0.65 (0.02)	0.57 (0.02)
Pr	0.63 (0.02)	0.58 (0.02)	0.58 (0.02)	0.59 (0.02)	0.51 (0.02)

Note: Standard errors of the mean are reported in parentheses. Neg-High = negative/high-arousal images, Neg-Low = negative/low-arousal images, Pos-High = positive/high-arousal images, Pos-Low = positive/low-arousal images.

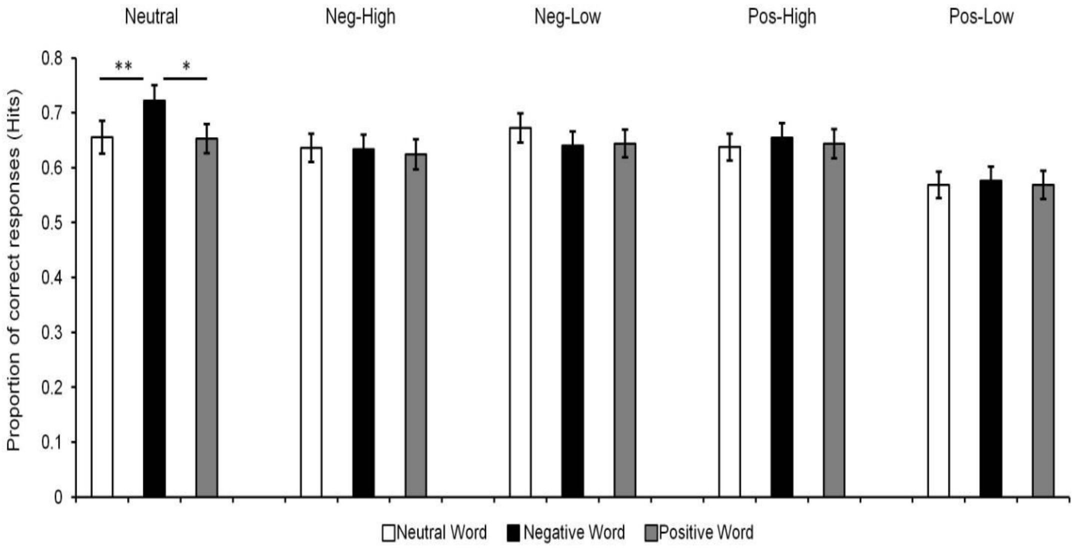


Figure 3. Histogram showing the influence of word valence on recognition performance across affective categories. Note: * $p < .1$, ** $p < .01$. Neg-High = negative/high-arousal images, Neg-Low = negative/low-arousal images, Pos-High = positive/high-arousal images, Pos-Low = positive/low-arousal images.

Personality and differential performance. The zero-order correlation coefficients for the hits, along with their 95% associated bootstrapped confidence intervals, are reported in Table 2. Overall, the results indicate that the influence of personality on recognition performance was restricted to BAS-Imp in the LTM group, regardless of condition and affective category. In the STM group, the BIS scale correlated positively with recognition memory in the full attention condition across affective categories (except for neutral images), while in the divided attention condition the influence of BIS was restricted to neutral and low-arousal emotional images. Further, BAS-tot and BAS subscales (except for BAS-RI) correlated negatively with the recognition performance of positive/high-arousal images in the divided attention condition. No other effects were observed, all p*s* > .05.

Table 2. *Zero-order correlations, along with their 95% associated bootstrapped confidence intervals, for the short-term memory and long-term memory group of the hits across affective categories and conditions with BIS, BAS, and BAS subscales (RI, RR, GDP, Imp).*

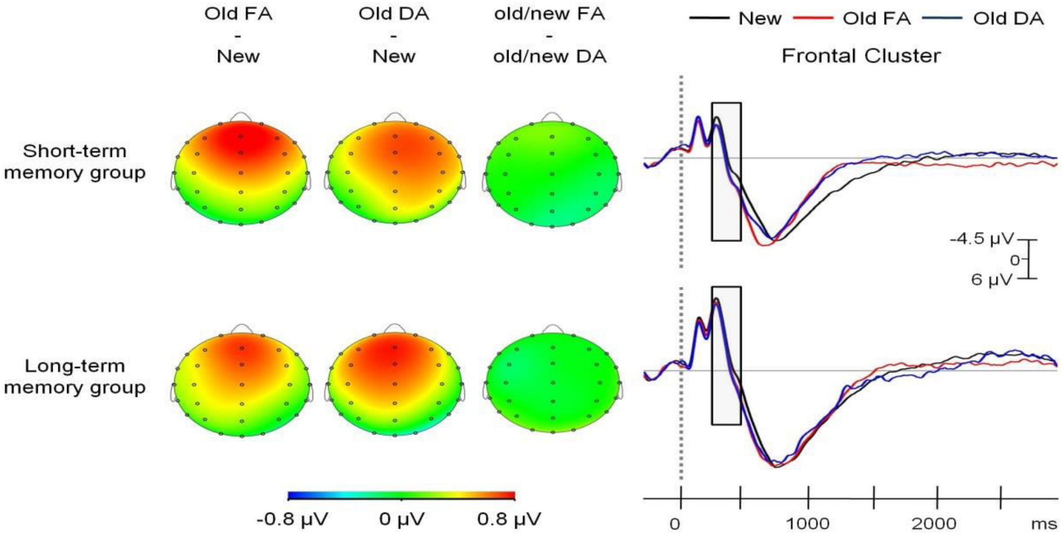
	Hits - Full Attention					Hits - Divided Attention				
Measure	Neutral	Neg-High	Neg-Low	Pos-High	Pos-Low	Neutral	Neg-High	Neg-Low	Pos-High	Pos-Low
(1) Short-term memory group										
BIS	0.29 (0.06, 0.47)	0.36* (0.11, 0.56)	0.38* (0.14, 0.57)	0.32* (0.14, 0.49)	0.32* (0.08, 0.50)	0.31* (0.11, 0.56)	0.27 (-0.06, 0.51)	0.31* (0.00, 0.57)	0.16 (-0.10, 0.40)	0.33* (0.09, 0.56)
BAS-tot	-0.06 (-0.34, 0.23)	-0.17 (-0.43, 0.08)	-0.08 (-0.40, 0.24)	0.13 (-0.18, 0.32)	0.08 (-0.26, 0.29)	-0.17 (-0.50, 0.17)	-0.26 (-0.49, 0.00)	-0.30 (-0.56, 0.01)	-0.33* (-0.54, -0.13)	-0.01 (-0.29, 0.25)
BAS-RI	-0.10 (-0.39, 0.24)	-0.18 (-0.42, 0.08)	-0.09 (-0.41, 0.27)	0.09 (-0.16, 0.27)	0.05 (-0.24, 0.25)	-0.06 (-0.42, 0.32)	-0.15 (-0.40, 0.13)	-0.30 (-0.57, 0.01)	-0.14 (-0.40, 0.11)	0.07 (-0.24, 0.35)
BAS-RR	-0.03 (-0.23, 0.30)	-0.21 (-0.44, 0.07)	-0.06 (-0.31, 0.24)	0.04 (-0.23, 0.22)	0.03 (-0.24, 0.20)	-0.22 (-0.47, 0.07)	-0.28 (-0.50, 0.01)	-0.25 (-0.48, 0.02)	-0.32* (-0.53, -0.09)	0.00 (-0.26, 0.25)
BAS-GDP	-0.05 (-0.39, 0.23)	-0.09 (-0.38, 0.16)	-0.07 (-0.35, 0.18)	0.22 (-0.21, 0.47)	0.17 (-0.23, 0.45)	-0.06 (-0.37, 0.25)	-0.20 (-0.50, 0.12)	-0.24 (-0.51, 0.08)	-0.31* (-0.57, -0.05)	-0.17 (-0.47, 0.15)
BAS-Imp	-0.02 (-0.32, 0.22)	-0.04 (-0.31, 0.20)	-0.03 (-0.41, 0.27)	0.05 (-0.13, 0.21)	-0.01 (-0.25, 0.18)	-0.14 (-0.42, 0.15)	-0.14 (-0.41, 0.12)	-0.13 (-0.43, 0.17)	-0.20 (-0.47, 0.06)	0.05 (-0.24, 0.33)
(2) Long-term memory group										
BIS	-0.06 (-0.39, 0.28)	-0.18 (-0.45, 0.11)	-0.26 (-0.51, 0.05)	-0.19 (-0.45, 0.10)	-0.16 (-0.46, 0.19)	-0.44** (-0.66, -0.12)	-0.06 (-0.37, 0.31)	-0.12 (-0.42, 0.19)	-0.29 (-0.58, 0.08)	-0.29 (-0.56, 0.08)
BAS-tot	-0.25 (-0.56, 0.12)	-0.21 (-0.49, 0.12)	-0.10 (-0.38, 0.23)	-0.13 (-0.41, 0.18)	-0.33 (-0.60, -0.03)	-0.16 (-0.47, 0.28)	-0.23 (-0.51, 0.12)	-0.04 (-0.37, 0.34)	-0.25 (-0.54, 0.12)	-0.22 (-0.49, 0.10)
BAS-RI	0.00 (-0.31, 0.32)	0.09 (-0.21, 0.38)	0.14 (-0.19, 0.44)	0.05 (-0.25, 0.34)	-0.07 (-0.39, 0.26)	0.15 (-0.16, 0.47)	0.07 (-0.26, 0.43)	0.14 (-0.17, 0.47)	0.08 (-0.26, 0.44)	0.05 (-0.28, 0.39)
BAS-RR	-0.14 (-0.48, 0.22)	-0.18 (-0.46, 0.12)	-0.05 (-0.36, 0.27)	-0.10 (-0.41, 0.24)	-0.32 (-0.61, 0.02)	-0.08 (-0.39, 0.29)	-0.25 (-0.53, 0.07)	0.04 (-0.29, 0.39)	-0.20 (-0.49, 0.16)	-0.14 (-0.42, 0.17)
BAS-GDP	-0.17 (-0.50, 0.20)	-0.10 (-0.51, 0.31)	0.06 (-0.33, 0.42)	0.08 (-0.28, 0.41)	-0.09 (-0.45, 0.29)	-0.13 (-0.47, 0.25)	-0.25 (-0.56, 0.15)	0.01 (-0.42, 0.41)	-0.18 (-0.48, 0.16)	-0.27 (-0.58, 0.05)
BAS-Imp	-0.45** (-0.68, -0.14)	-0.42* (-0.64, -0.16)	-0.40* (-0.59, -0.18)	-0.36* (-0.58, -0.13)	-0.51*** (-0.71, -0.25)	-0.40* (-0.65, -0.02)	-0.30 (-0.58, 0.02)	-0.29 (-0.52, -0.01)	-0.47*** (-0.70, 0.16)	-0.35* (-0.56, 0.07)

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.005$. Neg-High = negative/high-arousal images, Neg-Low = negative/low-arousal images, Pos-High = positive/high-arousal images, Pos-Low = positive/low-arousal images.

3.2 ERP data

Grand average ERPs across conditions (new, old-FA, old-DA) are shown in Figure 4, together with the overall difference maps of the ERP old/new differences for the early window (300 - 500 ms) and for the late window (500 - 800 ms).

(a) Early time window (300 – 500 ms)



(b) Late time window (500 – 800 ms)

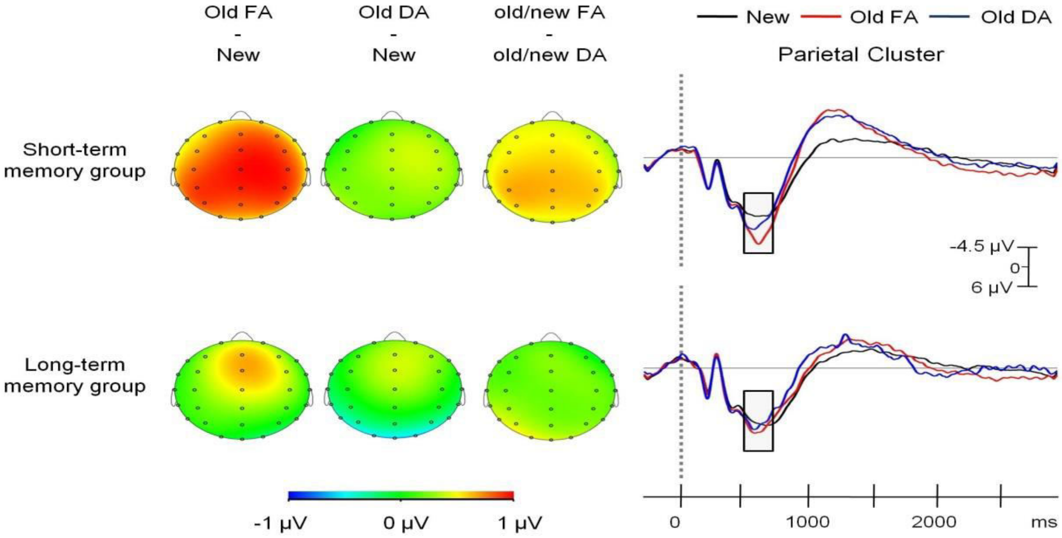


Figure 4. Difference scalp maps of the ERP old/new differences across conditions (new, old full attention, old divided attention) for (a) the early window (300 - 500 ms) and (b) the late window (500 - 800 ms). Grand averages are shown for the frontal and parietal cluster showing the ERPs for correctly classified new images (black line) and old images that were initially presented under conditions of full attention (red line) or under conditions of divided attention (blue line). The shaded area indicates the time interval used for the analysis of the early and late time window. The maps and ERPs are shown for or the short-term memory and long-term memory group. Note: Old FA = full attention, DA = divided attention.

3.2.1 Early time window: 300 – 500 ms

The results of the ANOVA revealed a main effect for Condition, $F(2,150) = 16.67$, $p < .0001$, $\eta^2_p = .18$. As can be seen in Figure 4, correctly classified old images previously presented during FA trials were associated with more positive waveforms over frontal sites than new images correctly classified as new, $F(1,75) = 24.83$, $p < .0001$, $\eta^2_p = .25$. Correspondingly, correctly classified old images previously presented during DA trials were associated with more positive waveforms than correctly classified new images, $F(1,75) = 32.77$, $p < .0001$, $\eta^2_p = .30$. ERP waveforms at frontal sites did not differ between the FA and DA condition, $F(1,75) < 1$. No Group differences (STM vs. LTM) were observed in the frontal ERP old/new effects, Condition x Group: $F(2,150) < 1$. ERP waveforms were modulated by the emotional content of the images, main effect for Emotion: $F(4,300) = 24.62$, $p < .0001$, $\eta^2_p = .25$, but the frontal ERP old/new effects did not vary as a function of emotional content of the images, Condition x Emotion: $F(6.78,507.71) = 1.30$, $p > .05$. The nonsignifiant interaction is plotted in Figure 5. The higher order interaction Condition x Emotion x Group failed to reach significance, $F(8,600) = 1.92$, $p > .05$.

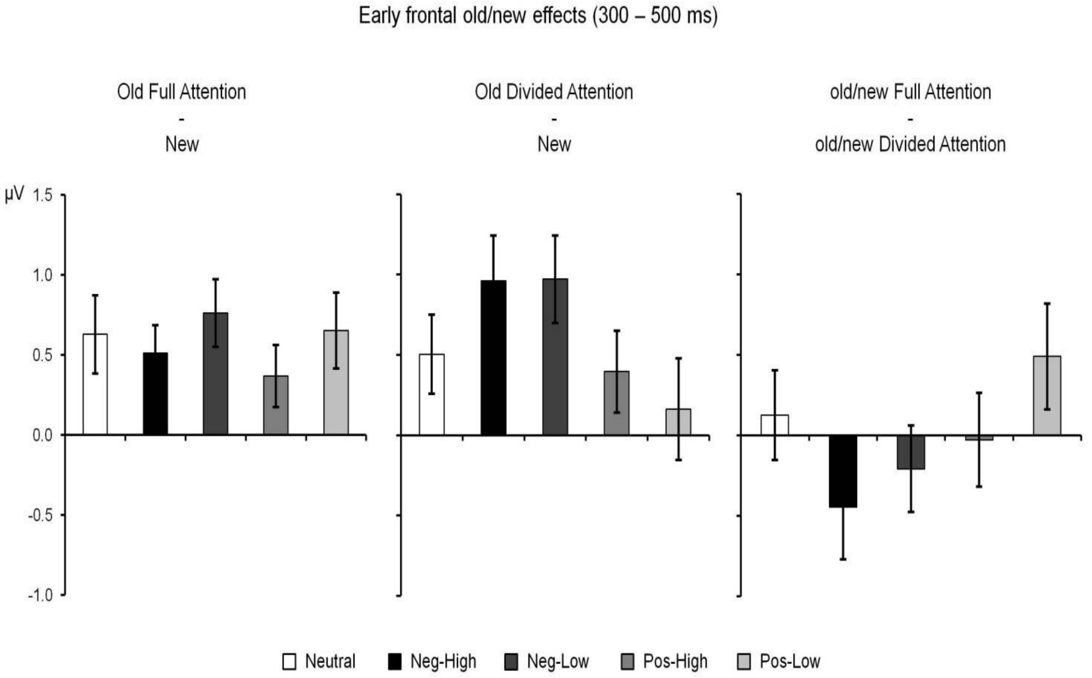


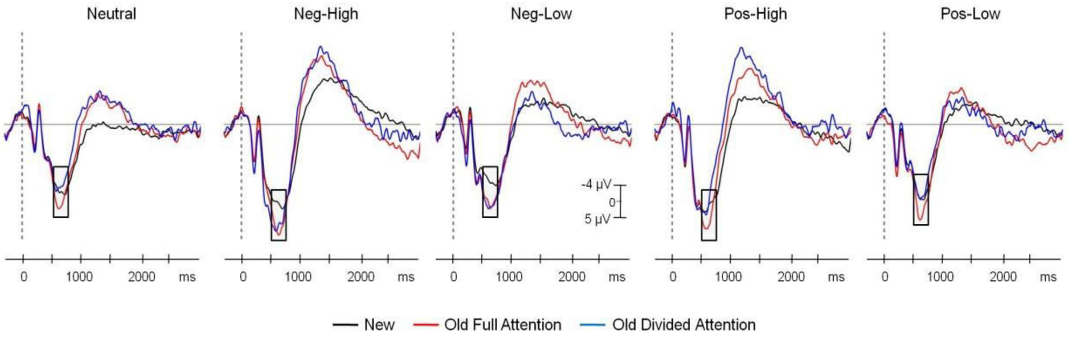
Figure 5. Histograms showing differences in old/new ERP amplitudes across conditions and affective categories for the early frontal old/new effect. Note: Neg-High = negative/high-arousal images, Neg-Low = negative/low-arousal images, Pos-High = positive/high-arousal images, Pos-Low = positive/low-arousal images.

3.2.2 Late time window: 500 – 800 ms

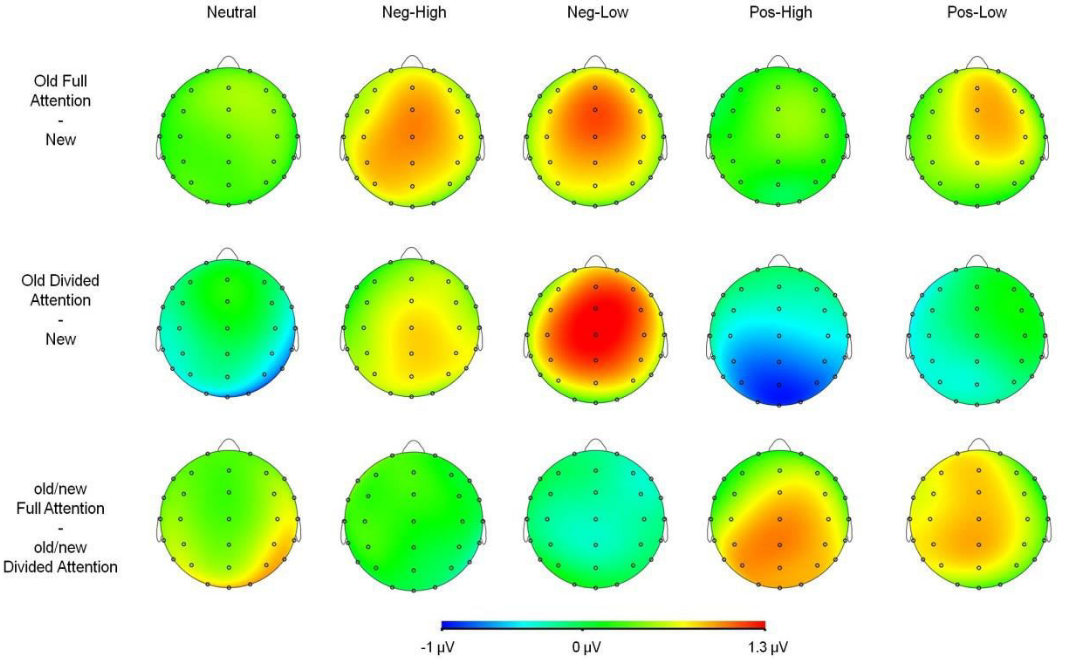
The ANOVA yielded a significant main effect for Condition, $F(2,150) = 8.13$, $p < .0001$, $\eta^2_p = .10$. Post-hoc comparisons indicated that correctly classified old images previously presented during FA trials were associated with more positive waveforms over parietal sites than new images correctly classified as new, $F(1,75) = 13.51$, $p < .0001$, $\eta^2_p = .15$. ERP waveforms did not differ between correctly classified old images previously presented during DA trials and correctly classified new images, $F(1,75) < 1$. Further, correctly classified old images previously presented during FA trials elicited more positive waveforms than correctly classified old images previously presented during DA trials, $F(1,75) = 11.87$, $p = .001$, $\eta^2_p = .14$. These ERP old/new effects differed between the STM and LTM group, Condition x Group: $F(2,150) = 6.44$, $p = .002$, $\eta^2_p = .08$. This interaction is plotted in Figure 4. Follow-up analyses revealed that the STM group showed ERP waveform differences across conditions, $F(2,82) = 14.29$, $p < .0001$, $\eta^2_p = .26$, but no old/new differences were observed for the LTM group, $F(2,68) = 1.40$, $p > .05$. The STM group showed the expected parietal ERP old/new effect with regard to old images previously presented during FA trials, $F(1,41) = 24.49$, $p < .0001$, $\eta^2_p = .37$, but not for old images presented during DA trials, $F(1,41) = 6.64$, $p = .022$ (*n.s.* after Bonferroni correction). Further, in the STM group correctly classified old images previously presented during FA trials elicited more positive waveforms than correctly classified old images previously presented during DA trials, $F(1,41) = 9.71$, $p = .003$, $\eta^2_p = .19$.

The ERP waveforms varied across emotional categories, main effect for Emotion: $F(4,300) = 15.73$, $p < .0001$, $\eta^2_p = .17$. More importantly, the parietal ERP old/new effect varied across emotional categories, Condition x Emotion: $F(6.94,520.71) = 3.58$, $p = .001$, $\eta^2_p = .05$. This interaction is illustrated in Figure 6. The higher-order interaction Condition x Emotion x Group failed to reach significance, $F(8,600) < 1$. Follow-up analyses demonstrated a significant Condition x Emotion interaction for the DA condition, $F(4,300) = 6.04$, $p < .0001$, $\eta^2_p = .07$, and a tendency for the FA condition, $F(4,300) = 2.06$, $p = .08$, $\eta^2_p = .03$, and a trend towards differences in ERP waveforms between the FA and DA condition, $F(4,300) = 1.99$, $p = .10$, $\eta^2_p = .03$. Regarding the FA condition, post-hoc comparisons indicated parietal old/new differences for negative/high-arousal images, $t(76) = 2.84$, $p = .006$, and negative low/arousal images, $t(76) = 4.08$, $p < .0001$. Neutral and positive/high-arousal images failed to show old/new differences, all p*s* > .05, whereas positive/low-arousal images showed a tendency for an old/new effect, *t*(76) = 1.85, *p* = .068. Using ERP difference values (old - new) to analyze the magnitude of the ERP old/new effects (e.g. Rugg, Schloerscheidt, & Mark, 1998), the results showed that the ERP old/new effects did not differ across affective categories, all p*s* > .05. Regarding the DA condition, the ERP old/new effect was still present for negative/low-arousal images, *t*(76) = 3.41, *p* = .001, while only a tendency for old/new differences was observed for negative/high-arousal images, *t*(76) = 2.28, *p* = .026 (*n.s.* after Bonferroni correction). Old positive/high-arousal images in the DA condition were associated with reduced positive ERP waveforms relative to new images, *t*(76) = 2.81, *p* = .006. Neutral and positive/low-arousal images showed no significant ERP old/new effects, all t*s* <1. Using ERP difference values, follow-up tests showed that negative/high-arousal images were associated with a stronger old/new effect relative to positive/high-arousal images, *t*(76) = 4.01, *p* < .0001.Correspondingly, negative/low-arousal images were associated with a stronger old/new effect relative to positive/low-arousal images, *t*(76) = 2.83, *p* = .006. Negative/low-arousal images showed a greater parietal old/new effect compared to neutral images, *t*(76) = 2.80, *p* = .007, while negative/high-arousal images showed a tendency for a stronger old/new effect relative to neutral images, *t*(76) = 1.96, *p* = .054. No other effects were observed, all p*s* > .05. Finally, ERP old/new effects between the DA and FA condition differed for positive/high-arousal images, *t*(76) = 3.47, *p* = .001, and a tendency was observed for positive/low-arousal images, *t*(76) = 2.32, *p* = .023 (*n.s.* after Bonferroni correction). Neutral and negative images showed no ERP old/new differences across conditions (FA vs. DA), all p*s* > .05.

(a) Parietal Cluster



(b) Difference maps showing the ERP old/new effects in the late time window (500 – 800 ms)



(c) Difference maps of the old/new differences (500 – 800 ms) for old images presented in the DA condition

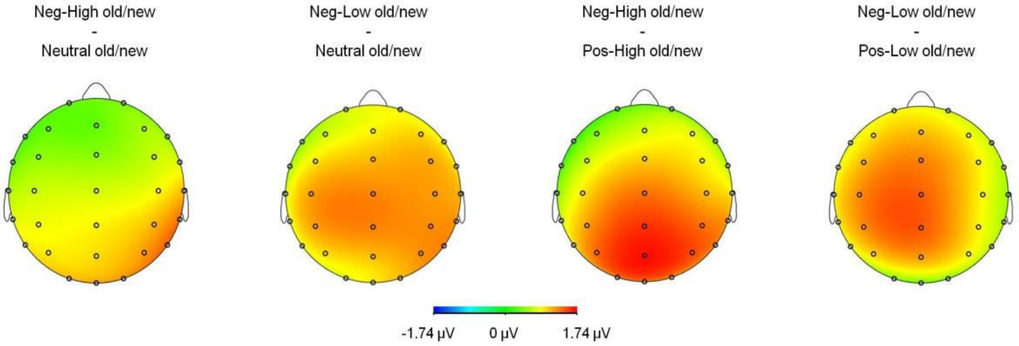


Figure 6. (a) ERP waveforms of the parietal cluster and (b) difference maps of the scalp distribution during the late time window (500 - 800 ms) showing the old/new differences for each affective category. The shaded area indicates the time interval used for the analysis of the late time window (500 - 800 ms). The ERP waveforms difference maps show the ERP old/new differences across attention conditions (full vs. divided). (c) Differences maps showing the old/new differences between affective conditions previously presented in the DA condition.

3.3 Correlations between physiological, behavioral, and trait variables

Bootstrap corrected zero-order correlations, regarding the relationship between the aforementioned parietal ERP old/new effects with behavioral measures (hits, Pr) and BIS/BAS measures (BIS, BAS-tot, BAS-RI, BAS-GDP, BAS-RR, BAS-Imp), were performed separately for the STM group and LTM group on single electrodes at centro-parietal sites (CP3, CPz, CP4, P3, Pz, P4). Results indicated that at CP4 the aforementioned negative parietal old/new effect for positive high-arousal images presented in the DA condition was associated with individual differences in BAS-RR and behavioral recognition performance.. No effects regarding the old/new effect for negative images were obtained, all *p*s > .05. The pertinent bootstrap corrected zero-order correlations are presented in Table 3.

Table 3. *Zero-order correlations, along with their 95% associated bootstrapped confidence intervals, means, and standard deviations of BAS-RR, hits, and the old/new difference at CP4 for positive high-arousal images in the old DA condition. The results are reported for the short-term (n = 42) and long-term memory group (n = 35).*

Variable	1	2	3	*M*	*SD*
(1) Short-term memory group					
Hit Pos-High (old DA)	1			0.74	0.16
CP4 Pos-High (old - new DA)	-0.46** (-0.67, -0.20)	1		-0.42	2.00
BAS-RR	-0.32* (-0.53, -0.09)	0.31* (0.05, 0.53)	1	27.02	5.20
(2) Long-term memory group					
Hit Pos-High (old DA)	1			0.53	0.16
CP4 Pos-High (old - new DA)	0.01 (-0.36, 0.31)	1		-0.85	2.30
BAS-RR	-0.20 (-0.49, 0.16)	-0.36* (-0.63, -0.02)	1	29.20	4.23

Note: * p < 0.05, ** p < 0.005. Pos-High = positive/high-arousal images, DA = divided attention.

Regarding the DA condition, a significant correlation was obtained between BAS-RR and parietal ERP old/new differences at CP4 for positive/high-arousal images. The direction of the correlation differed between groups (STM group: $r = .31$, $p < .05$, CI 95%: .05, .53; LTM group: $r = -.36$, $p < .05$, CI 95%: -.63, -.02). Using Fisher z-transformed correlations, the effect in the LTM group was significantly greater than in the STM group ($z = 2.92$, $p < .005$). This effect is illustrated in Figure 7.

Table 3 further indicates a mediator effect in the STM group, but not in the LTM group. Multiple regression analyses, as suggested by Baron & Kenny (1986), were used to examine the hypothesis that the ERP old/new difference for positive/high-arousal images mediated the influence of BAS-RR on subsequent recognition of positive/high-arousal images previously presented in the DA condition. The results of the separate regression steps are presented in Table 4.

Table 4. *Results of the test for mediation using a four step approach with several regression analyses.*

	Criterion	Predictor	B	*SE* B	β	*t*
Step 1	$Y = B_0 + B_1X + e$					
	Hit Pos-High (old DA)	BAS-RR	-.01	.01	-.32	-2.15*
				$F(1,40) = 4.61$, $R^2 = .10$*		
Step 2	$M = B_0 + B_1X + e$					
	CP4 Pos-High (old - new DA)	BAS-RR	.12	.06	.31	2.05*
				$F(1,40) = 4.20$, $R^2 = .10$*		
Step 3 and 4	$Y = B_0 + B_1X + B_1M + e$					
	Hit Pos-High (old DA)	BAS-RR	-.01	.01	-.20	-1.37
		CP4 Pos-High (old - new DA)	-.03	.01	-.40	-2.70*
				$F(2,39) = 6.31$, $R^2 = .25$**		

Note: * $p < 0.05$, ** $p < 0.005$. Pos-High = positive/high-arousal images, DA = divided attention.

Results indicated that BAS-RR significantly predicted the ERP old/new differences for positive/high-arousal images in the DA condition, $\beta = .31$, $t(41) =$

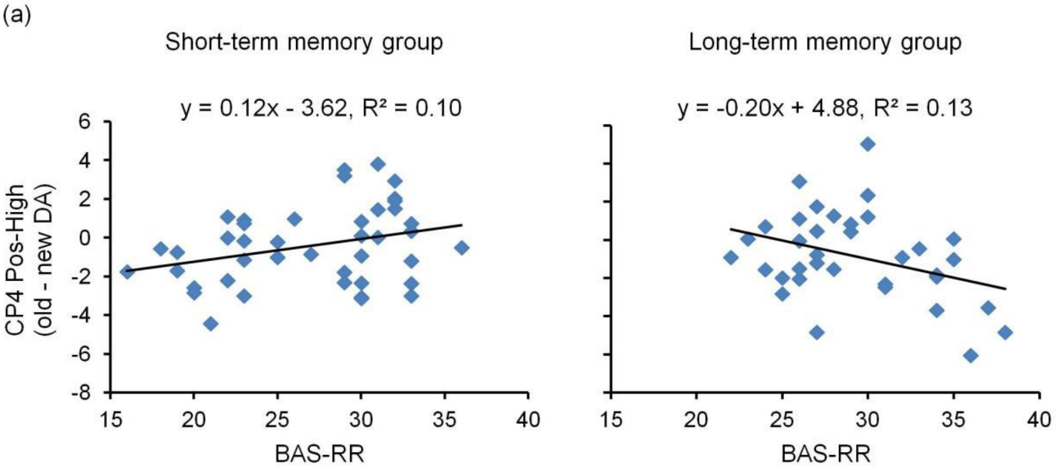
2.05, p = .047, and that the ERP old/new differences for positive/high-arousal predicted recognition performance for positive/high-arousal images in the DA condition, β = -.40, $t(41)$ = -2.70, p = .01. BAS-RR no longer predicted recognition performance after controlling for the mediator (i.e. ERP old/new difference for positive/high-arousal images), β = -.20, $t(41)$ = -1.37, p = .18, thus indicating full mediation. The meditational model accounted for 25% of the variance in the recognition performance for positive/high-arousal images in the DA condition. The statistical significance of the indirect effect were tested using a bootstrap method with 1000 samples (Shrout & Bolger, 2002). The indirect effect was significant, β = -.12, *SE* = .07, CI 95% = -.30, -.02. Thus, lower BAS-RR scores were associated with an increase of 12 % in recognition performance for positive/high-arousal images in the DA condition as mediated by the ERP old/new difference at CP4.

4. Discussion

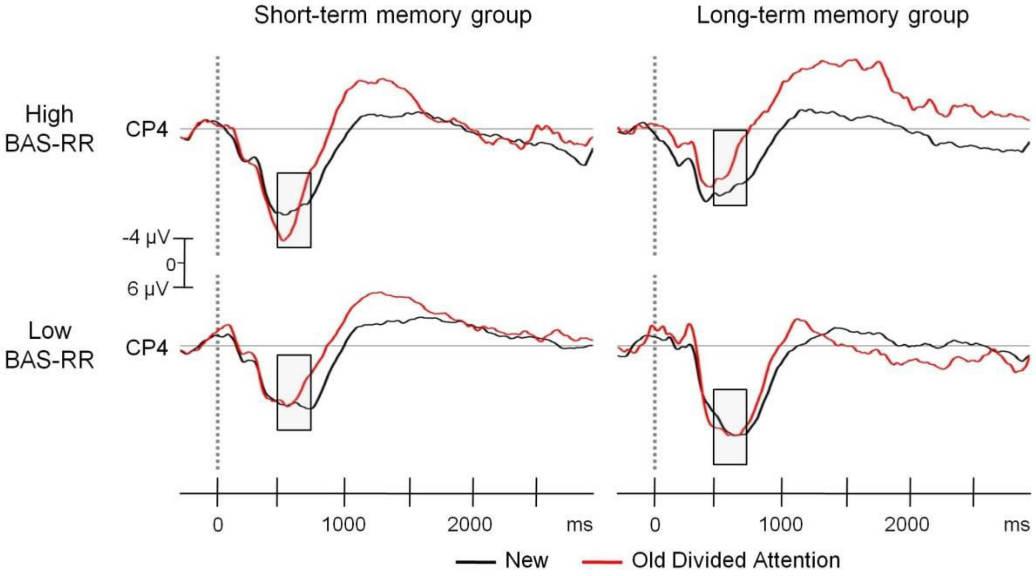
The current study investigated the influence of full and divided attention and the relative contribution of valence and arousal on the early frontal (300 - 500 ms) and late parietal (500 - 800 ms) ERP old/new effect underlying short-term and long-term recognition memory formation and retrieval. Although memory performance and the parietal old/new effect were reduced in the LTM group relative to the STM group, the results indicate that the emotional influence on memory formation remained resilient over time. Divided attention at encoding did not further modulate the influence of affective content on recognition memory performance, but electrophysiological results suggest that this is due to different underlying mechanisms. The parietal old/new differences associated with full attention were modulated by the valence value, while the valence and arousal value of affective stimuli influenced recognition memory and the late parietal ERP old/new effects associated with limited attention at encoding. Electrophysiological results suggest that visual attentional processes play a role in the recollection based recognition of positive/high-arousal images, but not of negative images, and this effect mediated the relationship between BAS-RR and recognition performance of positive/high-arousal images presented during DA trials.

As expected, divided attention decreased recognition memory performance compared to when images were passively viewed. Divided attention did not impact

(a)



(b) ERP waveforms elicited by Pos-High images



(c) Old/new difference maps (500 – 800 ms) for Pos-High images presented in the DA condition

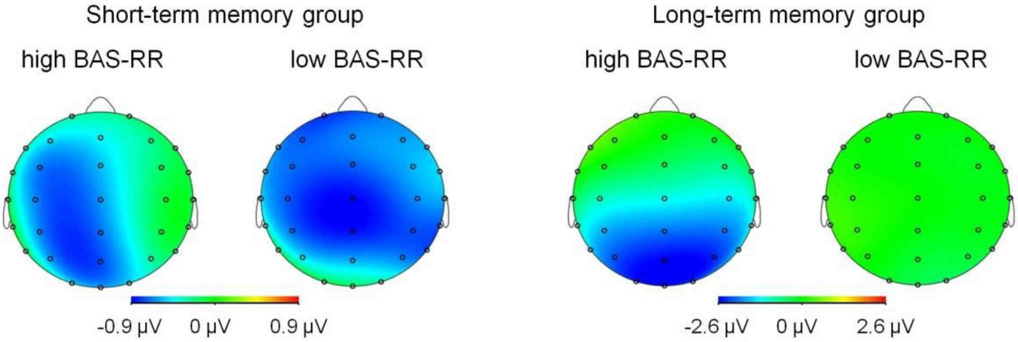


Figure 7. (a) Scatterplots showing the relationship between BAS-RR and old/new differences at CP4 for positive/high-arousal images from the divided attention (DA) condition. (b) ERP waveforms of new and old (DA) positive high/arousal images at CP4 comparing high and low BAS-RR participants. The shaded area indicates the time interval used for the analysis of the late time window (500 - 800 ms). (c) Difference maps comparing the old/new differences (500 - 800 ms) between high and low BAS-RR participants for positive/high-arousal images.

familiarity, as reflected by similar early frontal old/new effects for the FA and DA condition. Divided attention during encoding influenced recollection as indexed by a pronounced late parietal ERP old/new effect for the FA condition, while regarding the DA condition the parietal ERP waveforms did not differ between new and old images. Assuming that the frontal ERP old/new effect reflects familiarity (e.g., Rugg & Curran, 2007), the results imply that the neural generators of this component are unaffected by attention level (full vs. divided). In contrast, visual attention and preattentive processes play an important role for the formation and subsequent recollection of memories, as indexed by the absent parietal old/new effect in the DA condition. More importantly, while the STM group and LTM group showed similar frontal ERP old/new effects, the aforementioned parietal old/new effect in the FA condition was only present in the STM group. The LTM group failed to show reliable parietal ERP old/new differences for the FA condition as well as the DA condition. Overall, these results are in line with previous research showing an influence of time delay on the parietal old/new effect but not on the frontal ERP old/new effect (Roberts et al., 2013; Tsivilis et al., 2015). The observation that the parietal old/new effect in the FA condition was present in the STM group but not in the LTM group shows the reliance between the parietal old/new effect and the amount of recollected information (Vilberg, Moosavi, & Rugg, 2006; Wilding, 2000). However, this does not explain the lacking late parietal effect in the DA condition in both groups, since recollection was still higher in the STM compared to the LTM group. It may be that in the DA condition, recognition was mainly driven by familiarity rather than recollection. Unfortunately, we did not have participants perform remember/know judgments to clarify the relative contribution of recollection and familiarity in recognition performance to further examine this possibility.

In line with previous reports (Ochsner, 2000; Steinmetz & Kensinger, 2009; Xu et al., 2015), memory performance in the FA condition increased for high-arousal emotional images relative to low-arousal emotional images. Yet, while high-arousal emotional images did not differ in recognition performance, negative/low-arousal images were recognized better than positive/low-arousal images. The latter result, together with similar recognition accuracy for low and high-arousal negative stimuli, suggests that the memory benefit for negative stimuli is independent of arousal value, while the memory benefit for positive stimuli is not. In contrast to expectations, our behavioral results failed to indicate enhanced recognition memory performance for emotional images relative to neutral images. Some studies also failed to show increased memory accuracy for emotional relative to neutral stimuli (Jaeger et al., 2009; Van Strien et al., 2009; Weymar et al., 2013; Weymar, Löw, Schwabe, & Hamm, 2010). A possible explanation of this unexpected result may be that emotional images are more complex than neutral images (Lang, Bradley, & Cuthbert, 1997) and thus the reduced complexity may have aided the recognition performance for neutral images. Further, positive/low-arousal images were associated with impaired recognition performance compared to neutral images. This observation is in line with previous reports showing impaired memory performance for positive relative to neutral stimuli (Wang, 2014). Yet, while Wang (2014) used high-arousal emotional images, we observed the effect for low-arousal but not high-arousal positive images. Thus, it is possible that the low arousal value of the positive images together with the reduced complexity of neutral images resulted in greater recognition accuracy for neutral relative to positive/low-arousal images. The early frontal and late parietal ERP old/new effect showed the expected greater positivity of ERP waveforms for old images relative to new images. In concordance with prior studies (Johansson et al., 2004; Maratos et al., 2000; Weymar et al., 2009, 2013), the early frontal ERP old/new difference failed to show an influence of emotional valence and/or arousal on the magnitude of the old/new effects. Late parietal old/new differences were observed for low and high-arousal negative images, but not for neutral and positive images, regardless of arousal level. The latter results are in agreement with previous studies reporting a parietal old/new effect for negative but not positive or neutral stimuli (Inaba et al., 2005; Johansson et al., 2004). Thus, overall the current findings suggest that emotional valence and arousal do not affect the familiarity driven ERP old/ new effect, while emotional valence, but not arousal, exerts its effects on recollection and thus influences recognition performance (Maratos et al., 2000). The absent parietal old/new effect for neutral and positive images may be explained by the notion that recognition performance for negative items has been found to be based on recollection, while it has been found to be based on familiarity for positive and neutral items (Johansson et al., 2004; Maratos et al., 2000).

Behavioral results showed that full and divided attention did not differentially modulate the influence of emotions on memory performance. These results are in line with previous studies showing that impaired recognition memory under conditions of divided attention does not eliminate the memory benefit for emotional relative to neutral images (Kensinger & Corkin, 2004; Kern et al., 2005; Pottage & Schaefer, 2012; Steinmetz et al., 2014; Talmi et al., 2007; Talmi & McGarry, 2012). In contrast to expectations and previous studies (Clark-Foos & Marsh, 2008; Kensinger & Corkin, 2004), the level of attention (full vs. divided) did not have an effect on the memory performance for emotional images low in arousal. This discrepancy is likely due to modality differences in which the concurrent task is presented. In the aforementioned studies, the concurrent task relied on the auditory modality. Research has shown that when the attention task taps the auditory modality rather than the visual modality, no effect of attention on affective processing was observed (Schupp et al., 2008). In concordance, another study, in which the concurrent task tapped the visual modality, found no differential influence of attention level on memory performance for medium and low arousal negative images (Pottage & Schaefer, 2012). Another possible explanation lies in the notion that emotional stimuli are processed on a preattentive, automatic level (Christianson,1992). Our results show that the processing of negative and positive stimuli, regardless of arousal level, is unaffected by the level of attention and hence also low-arousal emotional images are processed in a preattentive manner. In contrast to the aforementioned behavioral results, the emotional modulation of the parietal old/new effect, but not the frontal ERP old/new effect, was influenced by the level of attention (full vs. divided). These results again support the view that valence exerts its effects on recognition by influencing recollection and not familiarity (Maratos et al., 2000). Parietal ERP old/new differences remained stable (FA vs. DA) for negative high and low-arousal images, and these effects were enhanced relative to the old/new effect for neutral images. These results suggest that attention is not necessary for the recollection of negative stimuli. In contrast to the negative images, divided attention at encoding resulted in an inverted parietal old/new effect (new > old) for positive/high-arousal images. Few studies have reported a negative parietal old/new effect (Addante, Ranganath, & Yonelinas, 2012; Maratos et al., 2000; Tsivilis et al., 2015). It has been suggested that this negative ERP old/new effect could reflect contextual familiarity (Addante et al., 2012). Contextual familiarity is hypothesized to reflect the activation of context information associated with item recognition in the absence of recollection, which then in turn supports source discrimination. Since we employed an item recognition paradigm and not a source memory paradigm, our negative parietal old/new effect for positive/high-arousal images is unlikely to reflect recollection based on contextual familiarity. Another view interprets the negative old/new effect as the capacity of new items to elicit spurious memories (Maratos, 2000). According to this view, the new positive/high-arousal images in our study could have been linked to ‘false’ memories and thus resulting in greater positivity for new images relative to old images. Since false alarms were low across conditions, this suggests that new positive/high-arousal images could still be distinguished from old positive/high-arousal images in the DA condition and thus preventing false alarms. However, our data show that the negative old/new difference is due to a reduced positivity for old images in the DA condition, and not due to a greater positivity for new positive/high-arousal images (Figure 6). This interpretation further fails to account for our observation that the parietal ERP old/new difference for positive/high-arousal images in the STM group correlated negatively with the hits in the DA condition. Thus, the inverted late parietal old/new effect in the current study must reflect some form of recollection due to the observed correlation with the behavioral performance data. This is further supported by the finding that positive/high-arousal images were better recognized than positive/low-arousal images. Yet, positive/low-arousal images failed to show a parietal old/new difference. Since no difference in recognition accuracy was observed between positive/high-arousal images and negative images, this further suggests that the positive parietal old/new difference and the negative old/new effect both reflect recollection based on different underlying mechanisms. While the behavioral data suggested that positive and negative images are processed in a preattentive manner, thus not requiring effortful elaboration, the results of the parietal old/new effect, however, suggest a different pattern. That is, we think that the negative parietal old/new difference for positive/high-arousal images reflects a more effortful search for the memory trace due to the divided attention at the encoding stage. Negative images appear to be recollected less effortful, even when attention at encoding was limited. At this point it should be noted that positive/high-arousal images did not show a parietal old/new effect for images initially viewed under full attention, suggesting that recognition was driven by familiarity rather than recollection. This apparent discrepancy between the FA and DA condition in the parietal old/new effect for positive/high-arousal images could indicate that old images presented in the DA condition were perceived with more uncertainty, therefore requiring more effortful elaboration, and thus resulting in recognition based on recollection.

Our interpretation of the negative parietal old/new effect is further supported by our findings regarding the relationship between individual differences in BAS-RR and the negative old/new effect at CP4. The negative correlation in the STM group suggests that low BAS-RR participants necessitated a more effortful search, while high BAS-RR participants, due to their increased sensitivity for reward and positive emotions (e.g., Gray & McNaughton, 2000), exhibited a more active, non-reflective search (i.e., disinhibition) as a result of the frustration associated with the more difficult recollection of positive images presented under limited attention (Patterson & Newman, 1993). The opposite pattern was observed in the LTM group, which indicates that time delay differentially influences the relationship between BAS-RR and the negative old/new difference. Since in the STM group, the negative old/new difference mediated the negative relationship between BAS-RR and recognition performance for positive/high-arousal images presented in the DA condition, we hypothesize that the aforementioned differences between low and high BAS-RR participants are due to differences in mental imagery of the earlier seen images stored in memory. Mental imagery of scenes (e.g., landmarks) has been shown to be related to increased activation of the right parahippocampal place area (O'Craven & Kanwisher, 2000) and to higher connectivity between the right parahippocampal place area and the right hippocampus (Boccia et al., 2017), which may explain why in the current study the difference was prominent at right centro-parietal sites (i.e. CP4). Thus, while a heightened BAS-RR sensitivity impairs recognition performance due to a lack of mental imagery at short time delays, a heightened BAS-RR sensitivity at long time delays appears to engage more effortful search strategies (e.g. mental imagery), which are unrelated to recognition performance. In contrast to expectations and previous studies (Gomez et al., 2004; Gomez & Gomez, 2002), the analyses of the behavioral and physiological data failed to yield additional reliable results for individual differences in the fear, anxiety, and approach systems. Overall, impulsivity was related to impaired performance in the LTM group, regardless of affective content. This finding is in line with the proposition that the impulsivity dimension reflects rash behavior without thinking about the consequences (Corr & Cooper, 2016). The impaired regulatory then resulted in impaired long-term recognition performance. The observation that the BIS was related to enhanced memory for neutral and low-arousal images in the STM group, especially under conditions of divided attention, is likely the result of enhanced attention associated with the activation of the BIS (e.g., Gray & McNaughton, 2000; McNaughton, & Corr, 2004). Further, BAS-GDP was related to impaired recognition of positive/high-arousal images that were presented during DA trials. Since no mediational effects by ERP old/new effects were observed with regard to BAS-GDP, this suggests that in contrast to the indirect influence of BAS-RR, BAS-GDP exerts a direct influence on the impaired recognition performance.

As expected, while the recognition performance decreased over time, the emotional modulation of the memory enhancement effect (behavioral data and ERP old/new effects) was not further influenced by group differences (STM vs. LTM) across conditions (full vs. divided attention). These results indicate that the emotional influence on memory formation remains resilient over time and that this resilience over time remains stable even when emotional images are processed under limited processing resources. The fact that time delay did not differentially affect memory performance for negative and positive low and high-arousal images is in line with previous reports (Talmi et al., 2007; Weymar et al., 2011), although another study observed that time delay impaired memory performance for positive images relative to negative images (Wang, 2014). Only one study assessed the influence of time delay (one week vs. one year) on the magnitude of the parietal ERP old/new effect across affective conditions (Weymar et al., 2011). The findings revealed that the enhanced ERP old/new effect for negative relative to neutral images remained stable, while the enhanced ERP old/new effect for positive relative to neutral images was no longer present after one year. In contrast, our results showed that negative low and high-arousal images in the FA condition demonstrated reliable old/new differences at both time points, while positive low and high-arousal images in the FA condition failed to show reliable old/new differences at both time points. The apparent discrepancy in the results may be due to the fact that in the current study positive images failed to elicit parietal old/new differences already at the short retention interval. Further, since recognition performance for positive stimuli has been found to be based on familiarity rather than recollection (Johansson et al., 2004; Maratos et al., 2000) and since familiarity, but not recollection, increases with time delay (Wang, 2014), this may further explain our nonsignificant group differences in the recollection sensitive parietal old/new effect for positive images. In contrast to previous findings showing impaired recall for neutral images in the DA condition over time (20 seconds vs. 50 minutes, Talmi et al., 2007), time delay in the current study did not further modulate the attenuated recognition performance in the DA condition across affective conditions. It is possible that the differences are due to the different retention intervals or due to inherent differences between recall and recognition (Gillund & Shiffrin, 1984), and/or due to the fact that in the study by Talmi et al. (2007) a within-subject design was employed while the current study used a between-subject design to examine the influence of time delay on recognition performance. In line with our behavioral results, time delay did not influence the magnitude of the parietal ERP old/new effect in the DA condition across affective conditions. Hence, the results of the current study show that the influence of emotion-attention interactions on memory functions independent of time.

Behavioral data showed that recognition memory for neutral images, but not negative and positive images, was influenced by the valence of the words presented during divided attention trials. Recognition memory for neutral images was enhanced when negative words were presented concurrently, relative to neutral and positive words. These results contrast previous findings showing that negative distractors impaired working memory performance for neutral stimuli relative to neutral distractors (Buchner et al., 2004; Dolcos & McCarthy, 2006), while positive distractors enhanced working memory performance relative to negative distractors (Iordan & Dolcos, 2017). Since working memory, short-term memory, and long-term memory represent different memory storage systems (e.g., McGaugh, 1966), the discrepancy in the results may reflect a differential influence of emotional distraction across memory systems. In contrast, the emotional valence of the negative and positive images was sufficient for recognition, so that recognition performance was further unaffected by word valence during divided attention trials. We did not perform separate analyses on the ERP data with regard to the influence of word valence on ERP old/new effects for the images. Our primary aim was to examine the neurophysiological correlates underlying the influence of attention on the emotional memory enhancement effect. We used neutral and emotional words to employ a concurrent emotional task, rather than a neutral task as generally done in previous research. Further, divided attention during encoding impaired memory performance to such a degree that the number of remaining trials for averaging was too low to compute separate ERPs based on word valence. Nonetheless, we do not believe that the emotional valence of the words limit the interpretation of our results as the overall valence of the words was neutral (*M* = 4.95, *SD* = .52).

In conclusion, the current study provides electrophysiological evidence showing that divided attention at encoding exerts a differential influence on recollection based recognition between negative and positive valenced images. Recollection of positive/high-arousal images requires a more effortful search for the memory trace, while negative images, regardless of arousal value, are recollected less effortful, even when attention at encoding is limited. The results have potential implications for disorders characterized by dysfunctional emotional memories, since the manipulation of attentional resources could help in the regulation of dysfunctional memory formation (Holmes, James, Killford, & Deeprose, 2010). Further, dysfunctional reward reactivity has been proposed to underlie disinhibited behavior (Gorenstein & Newman, 1980) and the results of the current study support this view by showing that a heightened reward reactivity is associated with impaired reflection in response to a positive stimulus, which then in turn impaired immediate recognition performance.

Chapter 5

The Late Posterior Negativity in Episodic Memory: A Correlate of Stimulus Retrieval?

This chapter is based on: Sommer, K., Vita, S., & De Pascalis, V. (under revision). The late posterior negativity in episodic memory: A correlate of stimulus retrieval?

Abstract

We investigated whether the late posterior negativity (LPN) is a component linked to stimulus retrieval or rather to stimulus evaluation or response preparation processes. Participants performed three separate tasks across separate sessions: an encoding task, a memory recognition task, and a visual discrimination task. In the visual discrimination task, the difficulty of stimulus evaluation was manipulated via stimuli varying in complexity (easy vs. moderately difficult) and duration of stimulus presentation (short vs. long). Three indices of the LPN peak were examined: amplitude, latency, and width. The LPN was present in all three tasks, with maximum amplitudes at occipital sites. Results of the visual discrimination task showed that the LPN amplitude is modulated by task difficulty. No latency differences were observed between short and long presentations, suggesting that the LPN is not related to response preparation. Consequently, we compared the LPN associated with short presentations of easy and difficult stimuli with the LPN of the encoding and memory task. The LPN amplitude was greater in the memory task compared to the other tasks. Latency and width of the LPN were modulated by stimulus complexity, with increased latency and width in the encoding and memory task relative to the visual discrimination task. Overall, these findings suggest that the LPN is not a component linked to stimulus retrieval and response preparation, but rather to stimulus evaluation processes, which are modulated by task difficulty.

1. Introduction

Various studies examining event-related potentials (ERP) during memory retrieval have reported a late posterior negativity component (LPN, 800-1200 ms), which has frequently been observed in source memory tasks but also in item memory tasks. In item memory tasks, the participant is required to make simple yes/no recognition judgments with regard to the presented material, whereas in source memory tasks the participant is required to recognize the presented stimulus as old or new and the context (e.g., background color) in which the stimulus was presented. The LPN is maximal at parietal-occipital sites, it has been found to be greater in response to old items than correctly rejected new items, and the LPN is often accompanied with a frontal positive slow wave. The functionality of the LPN is not clear, but it has been suggested that the LPN reflects action monitoring processes (e.g., Johansson and Mecklinger, 2003), response-related processes (e.g., Wilding and Rugg, 1997), and retrieval processes, i.e. reconstruction and evaluation processes (e.g., Johansson and Mecklinger, 2003; Mecklinger, Rosburg, & Johansson, 2016). The reader is referred to Johansson and Mecklinger (2003) and Mecklinger et al. (2016) for extensive reviews on the functionality of the LPN in episodic memory studies.

In item recognition tasks, the LPN has been hypothesized to reflect the involvement in action monitoring (including error-detection and conflict monitoring) in relation to the response. The LPN has been seldomly observed in mere item recognition tasks studies, but rather in item memory tasks that manipulated response selection demands or that employed a false recognition paradigm, in which false alarms were associated with prolonged reaction times. It has been assumed that when the experimental procedure gives rise to false alarms, the LPN may be linked to action monitoring processes due to response conflict (e.g., Curran, DeBuse, & Leynes, 2007; de Chastelaine, Friedman, & Cycowicz, 2007; Herron, 2007; Nessler, Mecklinger, & Penney, 2001; Nessler & Mecklinger, 2003). Specifically, the results of previous studies suggest that action monitoring processes contribute to the LPN when the stimulus-locked LPN is accompanied by response-locked error-related negativity (Johansson and Mecklinger, 2003; Mecklinger et al., 2016).

It has also been suggested that the LPN is related to response-related processes, because of observed associations between reaction time (RT) and LPN amplitude (e.g. Wilding & Rugg, 1997). Specifically, Wilding and Rugg (1997) observed that longer RTs were associated with greater LPN amplitudes and the correlations were strongest for false alarms, suggesting that the LPN reflects response-related processes rather than mnemonic processes. Correspondingly, additional support for a response preparation account of the LPN was obtained by the study by Kuo and Van Petten (2006). In this study, longer RTs associated with old items, compared to new items, were related to enhanced LPN amplitudes. In addition, the LPN was larger contralateral to the hand used to indicate recognition judgments for old items, which led the authors to suggest that the LPN reflects an extended Readiness Potential. Nevertheless, other studies failed to show RT differences between conditions that elicited an LPN and those that did not (e.g., Cycowicz, Friedman, & Snodgrass, 2001; Leynes & Bink, 2002; Rugg, Schloerscheidt, & Mark, 1998; Wilding & Rugg, 1996).

In source memory tasks, the LPN has been hypothesized to be involved in the reconstruction of the study episode by retrieving and evaluating attribute conjunctions, such as item-source and item-context associations (Johansson & Mecklinger, 2003; Mecklinger et al., 2016). It has been observed that the LPN in source memory tasks is not affected by the correctness of source judgments but rather by the amount of information that can be retrieved and with the specificity with which memory is searched (e.g., Leynes, Grey, & Crawford, 2006; Leynes & Kakadia, 2013; Mecklinger et al., 2016). That is, the LPN is smaller when contextual attributes are retrieved effortlessly and thus the amount of retrievable information is restricted (Mecklinger, Johansson, Parra, & Hanslmayr 2007).

Studies that confronted the LPN in item and source memory tasks observed greater LPN amplitudes in source memory tasks compared to item memory tasks (Cycowicz et al., 2001; Friedman et al., 2005; Senkfor & Van Petten, 1998). These findings suggest that the LPN may rather be modulated by task difficulty. This notion is further supported by the observation of better behavioral performance during in the item task relative to the source memory task (Cycowicz et al., 2001; Friedman, Cycowicz, & Bersick, 2005), although other studies noted the contrary (Johansson, Stenberg, Lindgren, & Rosén, 2002) or no differences in recognition performance between tasks (Senkfor & Van Petten, 1998). The inconsistent results may be due to task differences as the study by Johansson et al. (2002) employed a reality monitoring (perceived vs. imagined) paradigm, whereas the source memory tasks of the other studies had participants recognize the background color or gender of the voice in which the stimulus was presented initially. Source memory studies examining the LPN under conditions of reality monitoring and internal source monitoring have repeatedly shown that the LPN amplitude is greater for perceived than imagined stimuli, especially under conditions of internal source monitoring (Leynes, 2012; Leynes & Bink, 2002; Leynes & Kakadia, 2013). Further the LPN was found to be attenuated during reality monitoring relative to conditions of internal source monitoring. Since behavioral performance was found to be better during reality monitoring than during internal source monitoring, this again suggests that the LPN may be modulated by task difficulty. In concordance, a recent study has shown that when instructed to suppress a memory, this leads to a greater LPN amplitude when the participant is confronted with a probe of the to be suppressed stimulus during another task (Hu, Bergström, Bodenhausen, & Rosenfeld, 2015). One study that directly examined the influence of task difficulty on the LPN failed to find differences in LPN amplitude between easy and more difficult task conditions (Sprondel, Hipp, & mecklinger, 2012). However, this null-finding may be due to the fact that the behavioral performance did not differ between the easy and more difficult task condition, suggesting that the two conditions did not vary in task difficulty.

It is important to note that the LPN has mainly been observed and examined in memory studies. Few studies have reported potentials similar to the LPN in tasks that do not require explicit memory judgments (Brattico, Jacobsen, De Baene, Glerean, & Tervaniemi, 2010; Frings & Groh-Bordin, 2007; Schankin, Hagemann, Danner, & Hager, 2011). However, the LPN in these tasks often had an earlier onset, shorter duration, and a less restricted posterior topography as opposed to the LPN observed in memory tasks. Further, these studies are very heterogeneous, with the exception of the fact that all studies required the participants to make decisions based on what the participants had previously learned (e.g. grammar or music rules). Importantly, a recent study observed a LPN during the initial study phase occurring prior to the memory test that was modulated by the load of the study task (Yang, Wang, Yin, & Li, 2015). That is, the LPN amplitude was greater in the high-load than in the low-load condition. This observation is in line with our view that LPN may reflect general stimulus evaluation processes that are modulated by task difficulty.

The reviewed studies suggest an influence of action monitoring and retrieval processes (reconstruction and evaluation) on the LPN in episodic memory, while little support has been obtained for the involvement of response-related processes. The results of previous research further suggest an influence of task difficulty in the modulation of the LPN, although research is lacking that directly tested this hypothesis. Taking into account that few studies reported an LPN also in tasks that do not involve mnemonic processes, this suggests that the LPN reflects general stimulus evaluation processes that are modulated by task difficulty rather than memory specific processes. This view is further support by source memory studies showing that easily retrievable attributes elicit smaller LPN amplitudes compared to when attributes are not readily retrievable (Mecklinger et al., 2007, 2016). The aim of the current study was to address the hypothesis that the LPN reflects general stimulus evaluation processes which are modulated by task difficulty. A secondary aim of the current study was to examine the contribution of response preparation processes in the modulation of the LPN. Participants performed three separate tasks (encoding task, item recognition task, visual discrimination task). In the visual discrimination task, the difficulty of stimulus evaluation was manipulated via stimuli varying in complexity (easy vs. moderately difficult) and duration of stimulus presentation (short vs. long). Half of the participants performed the memory task 15 minutes after the encoding task (short-term memory group), while the other half of the participants performed the memory task one week after the encoding task (long-term memory group). Behavioral performance was expected to be better for easy task conditions (encoding task, short and long presentations of easy figures) than for more difficult task conditions (memory task, short and long presentations of difficult figures) and behavioral performance in the memory task was expected to be better in the short-term memory group compared to the long-term memory group. Three indices of the LPN were examined: amplitude, latency, and width. Visual inspection of the ERP waveforms indicated differences in the width of the LPN across tasks. We hypothesized that the width of the LPN reflects the duration of the ongoing elaboration processes and therefore included this measure in the analyses to gain a better understanding of the functionality of the LPN. With regard to the visual discrimination task, we expected the LPN amplitude and width to be greater during the presentation of difficult stimuli compared to easy stimuli. We further expected that the onset of the LPN would occur earlier in shorter stimulus presentations relative to longer presentations. In addition, it was assumed that the LPN amplitude and width would be greater under difficult task conditions (memory task, short presentations of difficult figures) than under easier task conditions (encoding task, short presentations of easy figures). Finally, we expected that the LPN (amplitude and width) in the memory task to be greater in the long-term memory group relative to the short-term memory group.

2. Method

2.1 Participants

Thirty-five students from the La Sapienza University of Rome participated in this study for course credit. Two participants were excluded from the analyses due to technical problems during the recordings. Another three participants were excluded due to poor performance in the memory task (> 2 SD from the mean performance of the total sample), leaving a total sample of 30 participants (21 females, 9 males) ranging in the age from 21 to 32 years (*M* = 24.07, *SD* = 2.70). Fifteen participants performed the memory task 15 minutes after the encoding task (short-term memory group; 5 males and 10 females) and the other 15 participants performed the memory task one week after the encoding task (long-term memory group; 4 males and 11 females). Participants reported no history of neurological or psychiatric disorders, and they reported no usage of certain medications and drugs that might interfere with the EEG recordings. Handedness was assessed via self-report and all participants were right-handed. Female participants performed the recordings outside of their menstrual period. The study was approved by the local ethics board and written informed consent was obtained from each participant.

2.2 Questionnaires

State Anxiety Inventory. The State Anxiety Inventory (STAI-Y1; Spielberger, Gorsuch, & Lushene, 1970) was used to assess state anxiety before and after each task. The STAI-Y1 consists of twenty items which ask to indicate how one feels in the moment, ranging from 1 (not at all) to 4 (very much so).

2.3 Experimental Tasks: Stimuli and Design

Participants performed three separate tasks: an encoding task, a memory task, and a visual discrimination task. All stimuli were presented on a monitor with a frame rate of 60 Hz (luminance of ~200 cd/m^2) and were viewed at a visual angle of 7.5° x 7.5°. A schematic of the trial structure for each task is presented in Figure 1.

2.3.1 Encoding and Memory Task

Stimuli. 600 images were selected from the International Affective Picture System (Lang, Bradley, & Cuthbert, 2008) and from the Geneva Affective Picture Database (Dan-Glauser & Scherer, 2011). The images were selected based on valence and arousal ratings obtained from 28 students. The ratings were obtained using a 9-point Likert Scale, ranging from 1 (*negative valence* or *low arousal*) to 9 (*positive valence* or *high arousal*). The final picture set consisted of 120 positive/low-arousal images, 120 positive/high-arousal images, 120 negative/low-arousal images, 120 negative/high-arousal images, and 120 neutral images. Two sets of 300 images were created, containing an equal amount of images from each affective category (i.e. 60). The sets did not differ with regard to valence (Set 1: M = 4.78, SD = 1.96; Set 2: M = 4.83, SD = 1.96, $t(598) = -.32$, $p > .05$) and arousal ratings (Set 1: M = 4.84, SD = 1.55; Set 2: M = 4.76, SD = 1.48, $t(598) = .63$, $p > .05$). One set served for the encoding task, while the other set served as the set of new images presented during the memory task. The order of the sets was counterbalanced across participants.

Trial Structure – Encoding Task. 300 images were presented in this task (60 positive/low-arousal images, 60 positive/high-arousal images, 60 negative/low-arousal images, 60 negative/high-arousal images, and 60 neutral images). The images were presented randomly in five blocks of 60 trials each, with the restriction that an equal number of images from each category (i.e., positive/low-arousal, positive/high-arousal, negative/low-arousal, negative/high-arousal pictures, and neutral) occurred in each block. For each picture category 30 images were presented during full attention trials and 30 images were presented during divided attention trials. In the current study, only the 150 image presented during full attention trials were considered for further analyses. Regarding the full attention trials, every trial started with the presentation of a fixation cross for 500 ms. Next, an emotional image was presented on the screen for three seconds. After the offset of each image, the participants were asked to make an approach/avoidance decision (Steinmetz, Waring, & Kensinger, 2014) in response to each image by pressing the corresponding button on a keyboard. The time to respond was limited to three seconds. Next, an intertrial interval (ITI) followed, varying between 4-5 seconds with a mean of 4.5 seconds, after which the next trial started.

Trial Structure – Memory Task. The 300 images of the encoding task were presented again, together with 300 new images, previously not seen. Every trial started with the presentation of a fixation cross for 500 ms. Next, an emotional image was presented on the screen for three seconds. After the offset of each image, the participants were asked to make yes/no recognition judgments. The time to respond was not limited. The images were presented randomly in three blocks of 200 images each, with the restriction that an equal number of images from each category (i.e., positive/low-arousal, positive/high-arousal, negative/low-arousal, negative/high-arousal pictures, and neutral) and each condition (new, old full attention, old divided attention) occurred in each block. For the purpose of the current study, only the 150 images presented during full attention, along with the newly presented images, were considered for further analyses.

2.3.2 Visual discrimination task

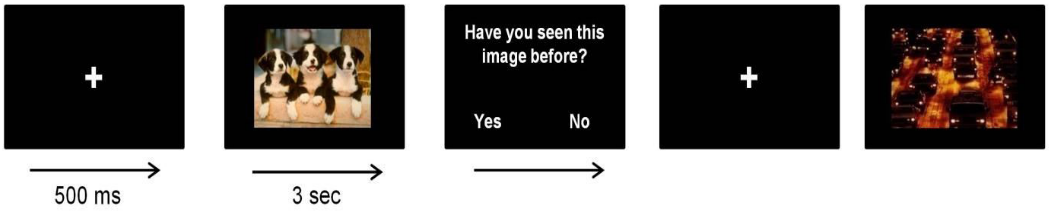
The visual discrimination task in the current study is a modified design of an experimental task adopted from a previous report (Becker, Hagemann, Bartussek, Naumann, & Schneider, 2004).

Stimuli. Stimuli were 400 regular and irregular geometrical figures with different number of sides (varying between three to seven), containing different number of dots (varying between three to eight). In a pilot study, five students rated the difficulty of each figure on a 4-point Likert scale, ranging from 1 (very easy) to 4 (very difficult). Based on the ratings, 200 very easy ($M_{\text{difficulty}} = 1.3$, $SD = 0.28$) and 200 moderately difficult ($M_{\text{difficulty}} = 2.96$, $SD = 0.37$) geometrical figures were selected.

Trial Structure. Every trial started with the presentation of a fixation cross for 500 ms. Next, a geometrical figure was presented on the screen for either three seconds or five seconds. After the offset of each figure, the participants were asked to make yes/no judgments, indicating whether the number of sides of the figure corresponded with the number of dots inside the figure. The time to respond was not limited. The figures were presented randomly in four blocks, with the restriction that an equal amount of easy and difficult geometrical figures was presented in each block. In two blocks the figures were presented for a shorter duration of three seconds, and in the other two blocks the figures were presented for a duration of five seconds. The order of blocks was randomized across participants.

(a) Encoding Task

(b) Memory Task



(c) Visual Discrimination Task

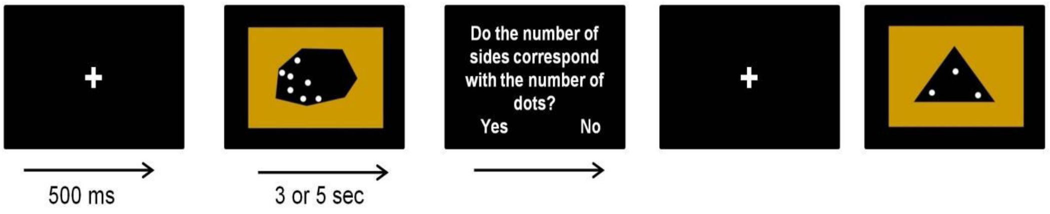


Figure 1. Schematic of the employed paradigms. Trial structure of the (a) encoding task, (b) memory task, and (c) visual discrimination task.

2.3 EEG Recordings and Data Reduction

EEG and electro-ocular (EOG) data were acquired continuously by using a 40-channel NuAmps DC amplifier system (Neuroscan Inc.), set at a gain of 200, sampling rate of 1024 Hz, and with signals band-limited to 500 Hz. A 50 Hz Notch filter was applied. Electrode impedances were kept below 5 kΩ. The EEG was recorded from 30 scalp sites according to the international 10-20 system (Fp1, Fp2, F7, F3, Fz, F4, F8, FT7, FT8, T3, T4, FC3, FCz, FC4, C3, Cz, C4, CP3, CPz, CP4, TP7, TP8, T5, T6, P3, Pz, P4, O1, Oz, O2), using a pure-tin electrode electrocap. Digitally linked earlobes [(A1 + A2)/2] served as reference electrode. The ground electrode was positioned 10 mm anterior to Fz. The vertical EOG was monitored by placing a pair of tin electrodes above and below the center of the left eye, while the horizaontal EOG was monitored by placing two electrodes 1 cm lateral to the outer cantus of each eye.

The EEG data was off-line processed with the Brain Vision Analyzer 2.1 system (Brain Product). The EEG signal was band-pass filtered at 0.10–50 Hz (slope 48 dB/octave). Data for rejected electrodes (Fp1, Fp2) were replaced with a statistically weighted interpolation from the full channel set. Ocular correction was performed using the Ocular Correction ICA tool, implemented in Brain Vision Analyzer. Epochs of 3300 ms, with a 300 ms pre-stimulus baseline, were used for each stimulus. Trials were rejected when they contained artifacts exceeding ±75 μV. Epochs of 5300 ms were used for the longer image presentations conditions in the visual discrimination task. The EEG was averaged across trials for each task and condition, smoothed using as moving average window of 60 ms, and then baseline corrected. To account for the different number of epochs across the tasks, regarding the encoding and memory task, the number of epochs used for averaging was limited to 100.

2.4 Procedure

Before the experiment started, the participants read and signed the informed consent. Next, the EEG electrodes were attached and participants were seated in a sound-attenuated and electrically shielded room where the recordings took place. Before and after each task, participants filled in the STAI-Y1. The short-term memory group (STM; n = 15) performed the memory task 15 minutes after the encoding task, while the long-term memory group (LTM; n = 15) performed the memory task one week after the encoding task. The participants were not informed that their memory would be tested subsequently. The visual discrimination task was performed in a separate session. Speed and accuracy in responding was stressed in all three tasks.

2.5 Data Analysis

EEG, and electro-ocular (EOG) data were acquired continuously by using a 40-channel NuAmps DC amplifier system (Neuroscan Inc.), set at a gain of 200, sampling rate of 1024 Hz, and with signals band-limited to 500 Hz. A 50 Hz online Notch filter was applied. Electrode impedances were kept below 5 kΩ. The EEG was recorded from 30 scalp sites according to the international 10-20 system (Fp1, Fp2, F7, F3, Fz, F4, F8, FT7, FT8, T3, T4, FC3, FCz, FC4, C3, Cz, C4, CP3, CPz, CP4, TP7, TP8, T5, T6, P3, Pz, P4, O1, Oz, O2), using a pure-tin electrode electrocap. Digitally linked earlobes [(A1 + A2)/2] served as reference electrode. The ground electrode was positioned 10 mm anterior to Fz. The vertical EOG was monitored by placing a pair of tin electrodes above and below the center of the left eye, while the horizontal EOG was monitored by placing two electrodes 1 cm lateral to the outer cantus of each eye.

The EEG data was off-line processed with the Brain Vision Analyzer 2.1 system (Brain Product). The EEG signal was band-pass filtered at 0.10–50 Hz (slope 48 dB/octave). Data for rejected electrodes (Fp1, Fp2) were replaced with a statistically weighted interpolation from the full channel set. Ocular correction was performed using the Ocular Correction ICA tool, implemented in Brain Vision Analyzer. Epochs of 3300 ms, with a 300 ms pre-stimulus baseline, were used for each stimulus. Trials were rejected when they contained artifacts exceeding ±75 μV. Epochs of 5300 ms were used for the longer image presentations conditions in the visual discrimination task. The EEG was averaged across trials for each task and condition, smoothed using as moving average window of 60 ms, and then baseline corrected. To account for the different number of epochs across the tasks, regarding the encoding and memory task, the number of epochs used for averaging was limited to 100. Regarding the visual discrimination task, the mean number of epochs used for averaging ranged between 81 and 98 epochs (easy-short: $M = 97$, easy-long: $M = 98$, difficult-short: $M = 81$, difficult-long: $M = 90$).

2.5 Procedure

Before the experiment started, the participants read and signed the informed consent. Next, the EEG electrodes were attached and participants were seated in a sound-attenuated and electrically shielded room where the recordings took place. The short-term memory group (STM; n = 15) performed the memory task 15 minutes after the encoding task, while the long-term memory group (LTM; n = 15) performed the memory task one week after the encoding task. The participants were not informed that their memory would be tested subsequently. The visual discrimination task was performed in a separate session on a separate day, following the encoding and memory task. The participants performed the visual discrimination task within one week to five months after the completion of the memory task. Before and after each task, participants filled in the STAI-Y1. Speed and accuracy in responding was stressed in all three tasks.

2.6 Data Analysis

Three indices of the LPN were analyzed: peak amplitude, peak latency, and width of the peak. An automated peak detection function first identified the maximum peak amplitude of the LPN within a set time window (700 - 1200 ms) and then each selection was visually inspected and manually adjusted, where necessary. Peak latency was measured as the time point in which the LPN reached the maximum amplitude. The width time (ms) of the LPN was measured as the difference of two time axis projections corresponding to the two amplitude values on the LPN wave, obtained by the intersection of a straight line, parallel to the time axis, with the LPN waveform. The amplitude value of the straight line was obtained by dividing the maximum value of the LPN waveform by the square root of two ($y = \max_x/\mathrm{sqrt}(2)$). The width time measure was calculated manually for each participant and therefore it should not affect measures of later and more variable ERP components. This LPN measure was included in the analyses assuming that it represents a good index of the duration of the ongoing elaboration processes.

First, amplitude, latency, and width data of the LPN of the visual discrimination task were analyzed using an 2 x 2 x 3 ANOVA for repeated measures with Task difficulty (easy, moderately difficult), Image duration (short, long), and Electrode site (O1, Oz, O2) as within-subject factors to assess whether the LPN is modulated by task difficulty and/or the duration of image presentation. Subsequently, a 4 x 3 x 2 ANOVA was performed with Condition (encoding, easy-short, difficult-short, memory) and Electrode site (O1, Oz, O2) as within-subject factors and Group (STM, LTM) as between subject factor. Behavioral data, i.e., proportion of correct responses (hits) and reaction time) were analyzed using the aforementioned analyses, with the exception of the within-subject factor electrode position. Further, to control for mood differences of the participants across tasks and sessions, an additional ANOVA for repeated was performed on STAY-Y1 differences scores (after - before) with Task as within-subject factor and Group (STM, LTM) as between subject factor. Where appropriate, Bonferroni corrected follow-up comparisons were conducted on significant main and interaction effects ($\alpha = 0.05$). In instances where the assumption of sphericity was violated, degrees of freedom were adjusted using Huynh-Feldt adjustments. Finally, zero-order correlations were performed between conditions (encoding, easy-short, difficult-short, memory) for each electrode site (O1, Oz, O2) across the LPN indices (amplitude, latency, width) to evaluate the assumption that the same component is studied in all tasks.

3. Results

3.1 State-Anxiety

The analysis failed to yield significant differences in the mood of the participants (i.e. state anxiety) across tasks, $F(2,56) = 1.52$, $p > .05$, regardless of group membership (STM vs. LTM), $F(2,56) < 1$, $p > .05$.

3.2 Behavioral Performance

Regarding the visual discrimination task and the memory task, descriptives (means and standard deviations) of the proportions of correct responses (i.e. Hit) and the associated reaction times are reported in Table 1.

3.2.1 Visual Discrimination Task

Analyses done on the hits of the visual discrimination task revealed the expected two-way interaction between Task difficulty x Image duration, $F(1,29) = 31.04$, $p < .0001$, $\eta^2_p = .52$. Follow-up contrasts indicated that easy geometrical figures were associated with increased hits relative to difficult geometrical figures, during short presentations, $t(29) = 9.37$, $p < .0001$, as well as during long image presentations, $t(29) = 6.94$, $p < .0001$. No differences in performance were observed for easy geometrical figures during short and long image presentations, $t(29) = -.50$, $p > .05$, while difficult geometrical figures presented for longer durations were associated with better performance than difficult geometrical figures presented for shorter durations, $t(29) = -5.42$, $p < .0001$.

Correspondingly, the ANOVA performed on the RT data also revealed an interaction between Task difficulty x Image duration, $F(1,29) = 43.09$, $p < .0001$, $\eta^2_p = .60$. Follow-up analyses indicated that easy geometrical figures were associated with faster RTs than difficult geometrical figures, during short and long image presentations, all *p*s < .001. Long presentations of difficult geometrical figures were related to faster RTs than short presentations of difficult geometrical figures, $t(29) = -$

5.78, $p < .0001$, while no differences in RT were observed between short and long presentations of easy geometrical figures (*n.s.* after Bonferroni correction).

3.2.2 Task Difficulty: Visual Discrimination Task vs. Memory Task

The ANOVA performed on the hits of the visual discrimination task and memory task demonstrated a significant interaction between Task x Group, $F(2,56) = 4.69$, $p < .05$, $\eta^2_p = .14$. Follow-up contrasts showed that in the STM group, short presentations of easy figures were associated with a better performance than the memory task, $t(14) = 7.79$, $p < .0001$, while no performance differences were observed between short presentations of difficult stimuli and the memory task, $t(14) = .27$, $p > .05$. In contrast, in the LTM group, short presentations of easy and difficult stimuli were linked to a better performance than the memory task, easy: $t(14) = 21.94$, $p < .0001$; difficult: $t(14) = 3.49$, $p < .005$. Consequently, behavioral performance during the memory task was better for the STM group compared to the LTM group, $t(28) = 3.34$, $p < .005$. The ANOVA performed on the RT data yielded no RT differences between the groups during the memory task, $t(28) = .56$, $p > .05$. No group differences in behavioral performance and RT were observed for the visual discrimination task, all *p*s > .05.

Table 1. *Means and standard deviations for the proportions of correct responses (Hit) and reaction times (RT, ms), respectively, for the visual discrimination task and memory task. Descriptives regarding the memory task are reported across all participants, and separately for the short-term (STM) and long-term (LTM) memory group.*

	Easy Short	Easy Long	Difficult Short	Difficult Long	Memory (n = 30)	STM (n = 15)	LTM (n = 15)
Hit	0.97 (0.03)	0.98 (0.04)	0.81 (0.12)	0.90 (0.08)	0.75 (0.09)	0.80 (0.10)	0.70 (0.05)
RT	491 (174)	535 (208)	1013 (516)	679 (324)	458 (171)	476 (215)	441 (120)

3.2 Visual Discrimination Task

Figures 2 shows the ERPs for each condition across electrode sites (O1, Oz, O2). The ANOVA performed on the LPN amplitude yielded a significant main effect for Task difficulty, $F(1,29) = 12.05$, $p < .005$, $\eta^2_p = .29$, indicating that presentations of difficult geometrical figures were associated with greater LPN amplitudes compared to easy geometrical figures. This effect tended to vary as a function of image duration, Task difficulty x Image duration, $F(1,29) = 3.91$, $p = .057$, $\eta^2_p = .12$. Follow-up contrasts indicated that short presentations of difficult figures were associated with greater LPN amplitudes relatives to short presentations of easy geometrical figures, $t(29) = 4.03$, $p < .0001$. No other differences were observed, all ps > .05. The higher-order interactions Task difficulty x Electrode site, Image duration x Electrode site, and Task difficulty x Image duration x Electrode site failed to reach significance, all ps > .05. In contrast to expectation, the results of the ANOVA done on the latency data of the LPN showed no latency differences across conditions, all ps > .05.Finally, the analysis performed on the LPN width revealed no influence of task difficulty, $F(1,29) = 1.56$, $p > .05$, while it demonstrated a significant main effect for Image duration, $F(1,29) = 11.20$, $p < .005$, $\eta^2_p = .28$, indicating that short presentations of geometrical figures were associated with a reduced width of the LPN peak relative to long presentations of geometrical figures. This effect was not further modulated by task difficulty and also the higher-order interaction Task difficulty x Image duration x Electrode site failed to reach significance, all ps > .05.

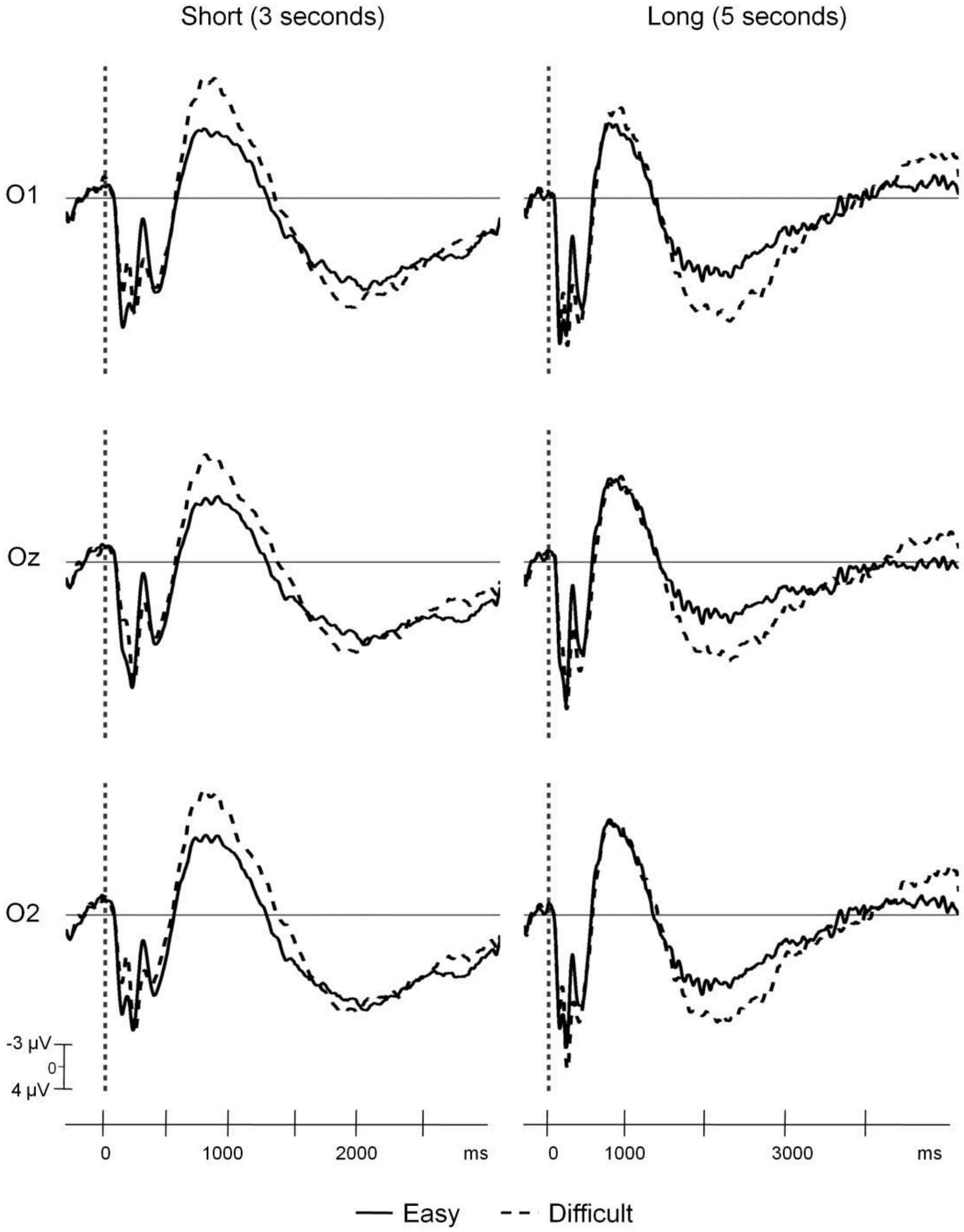


Figure 2. ERPs during the visual discrimination task. ERP waveforms at occipital sites (O1, Oz, O2) comparing easy and difficult stimuli during (a) short image presentations (three seconds) and (a) long image presentations (five seconds).

3.3 Visual Discrimination Task vs. Encoding Task vs. Memory Task

Figures 3 shows the ERP amplitudes at occipital sites (O1, Oz, O2) across tasks for all participants and separately for the STM and LTM group. The scalp maps in Figure 4 show the distribution of the LPN across tasks.

3.4.1 LPN Amplitude

The ANOVA done on the LPN amplitude data demonstrated a significant main effect for Condition, $F(3,84) = 9.51$, $p < .0001$, $\eta^2_p = .25$. Follow-up analyses revealed that the LPN amplitude associated with the encoding task showed reduced negativity, compared to the LPN associated with the memory task, $t(29) = -4.07$, $p < .001$, and the LPN associated with the short presentations of difficult figures during the visual discrimination task, $t(29) = -2.15$, $p < .05$. No difference in LPN amplitudes were observed between the encoding task and the short presentations of easy figures during the visual discrimination task, $t(29) = -.12$, $p = .90$. Finally, the LPN amplitude associated with the memory task demonstrated increased negativity relative to the LPN associated with short presentations of easy figures, $t(29) = 3.91$, $p < .001$, and difficult figures, $t(29) = 2.67$, $p < .05$, during the visual discrimination task. The higher-order interactions Condition x Electrode site, Condition x Group, and Condition x Electrode site x Group failed to reach significance, all *p*s > .05.

3.4.2 LPN Peak Latency

The results of the ANOVA on the LPN latency data showed a significant main effect for Condition, $F(3,84) = 11.1$, $p < .0001$, $\eta^2_p = .28$. Follow-up contrast yielded no latency differences between the encoding task and memory task, $t(29) = -.67$, $p = .51$. Short presentations of easy figures were associated with an earlier onset of the LPN amplitude, compared to the encoding task, $t(29) = 4.03$, $p < .0005$, and the memory task, $t(29) = 3.60$, $p < .01$. Correspondingly, short presentations of difficult figures were associated with an earlier onset of the LPN amplitude, relative to the encoding task, $t(29) = 3.94$, $p < .001$, and the memory task, $t(29) = 3.82$, $p < .001$. The higher-order interactions Condition x Electrode site, Condition x Group, and Condition x Electrode site x Group failed to reach significance, all *p*s > .05.

3.4.3 LPN Width

Regarding the width of the LPN amplitude, the ANOVA yielded a significant main effect for Condition, $F(3,84) = 5.52$, $p < .005$, $\eta p^2 = .16$. Follow-up analyses demonstrated no differences in the width of the LPN peak between the encoding task and the memory task, $t(29) = -1.21$, $p = .24$. Further, no differences in LPN width were observed between the encoding task and short presentations of easy figures, *t*(29) = 1.88, *p* = .07, and between the encoding task and short presentations of difficult figures, *t*(29) = 1.84, *p* = .08. In contrast, the memory task was associated with a greater width of the LPN peak relative to short presentations of easy figures, *t*(29) = 3.53, *p* < .005, and short presentations of difficult figures, *t*(29) = 3.66, *p* = .005. The higher-order interactions Condition x Electrode site, Condition x Group, and Condition x Electrode site x Group failed to reach significance, all *p*s > .05.

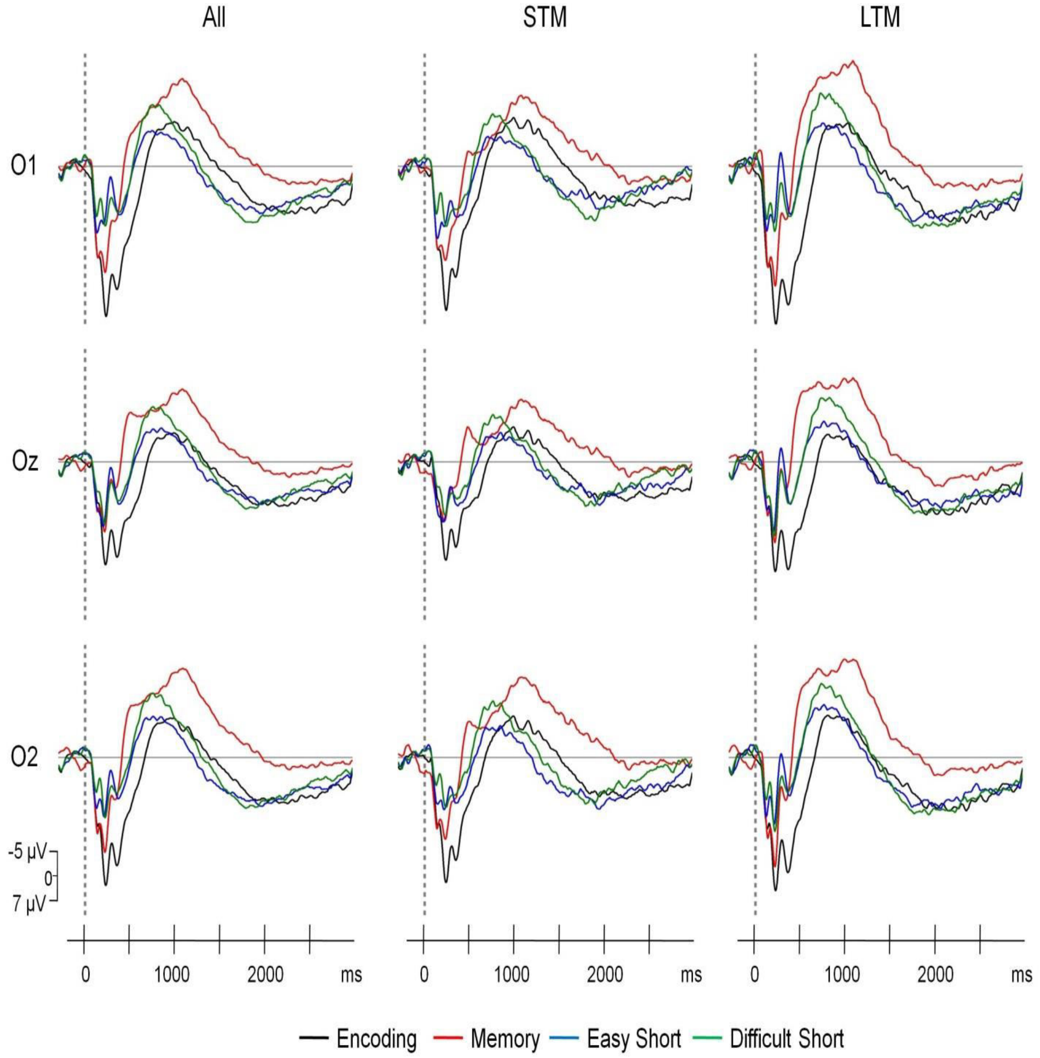


Figure 3. A comparison of the LPN across tasks. ERP amplitudes at occipital sites (O1, Oz, O2) showing the LPN amplitude across tasks (i.e., encoding task, memory task, and visual discrimination task) for all participants and separately for the STM group and the LTM group.

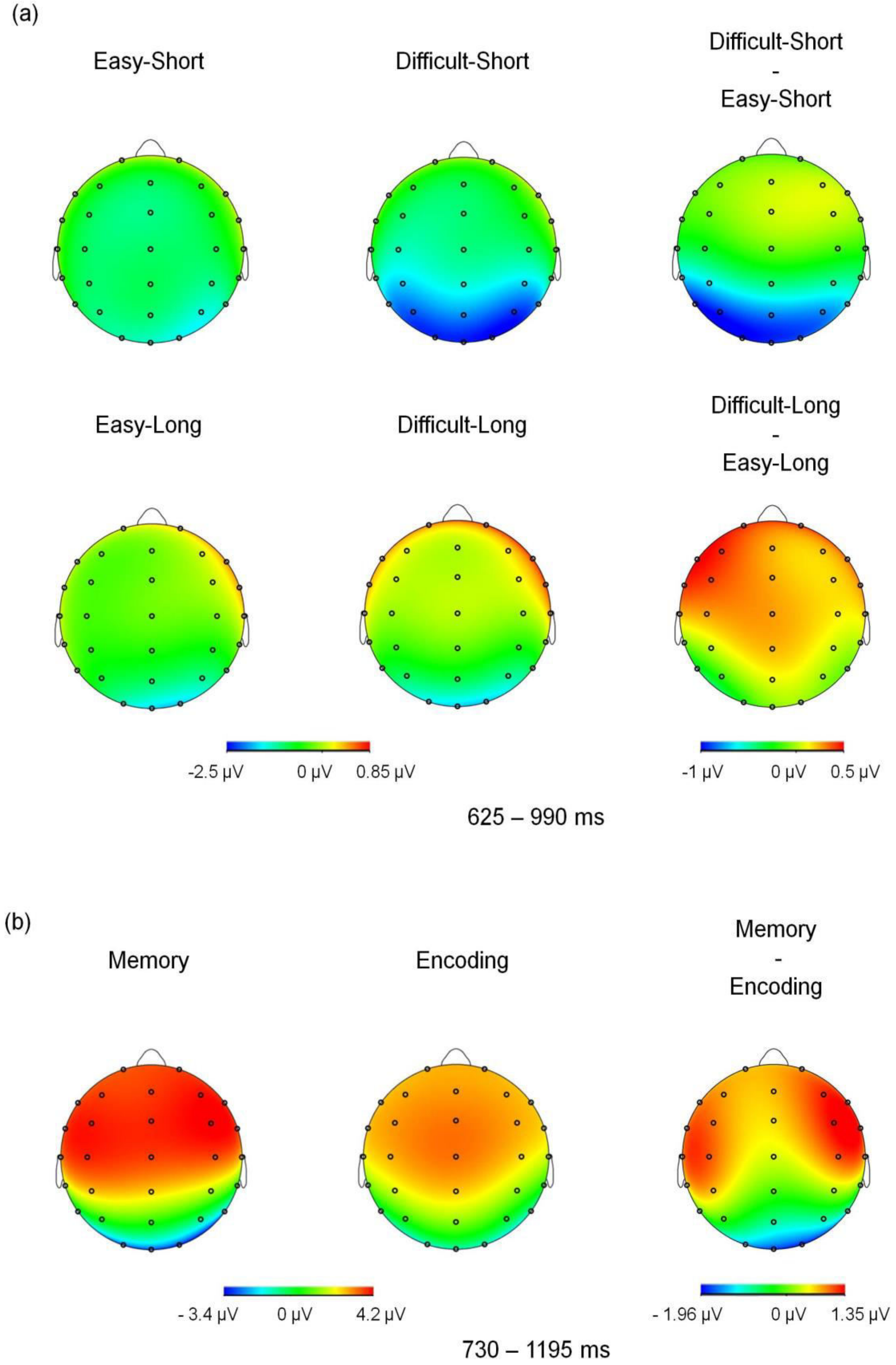


Figure 4. Scalp map differences in the LPN across task. Scalp maps and difference maps of the LPN in the visual discrimination task (a) and in the encoding and memory task (b).

3.4.4. Correlational Analyses

Zero-order correlations were performed between conditions (encoding, easy-short, difficult-short, memory) for each electrode site (O1, Oz, O2) across the LPN indices (amplitude, latency, width). The results of the correlational analyses are reported in Table 2. It can be seen that regarding peak amplitude and latency of the LPN, the task conditions correlated across occipital electrode sites, while correlations were lacking with regard to the width of the LPN.(with the exception of the positive relationship between encoding task and memory task and Oz and O2). More difficult task conditions (i.e. memory and short presentations of difficult figures) were associated with greater correlation coefficients, especially with regard to the amplitude of the LPN. In addition, the peak latency of the LPN correlated strongly between the encoding task and memory task across electrode sites.

Table 2. *Zero-order correlations between conditions (encoding, easy-short, difficult-short, memory) for each electrode site (O1, Oz, O2) across the LPN indices (amplitude, latency, width).*

	Electrode Site		
Comparison	O1	Oz	O2
a) Amplitude			
Encoding vs. Memory	.13	.17	.16
Encoding vs. Easy-Short	-.02	-.01	-.04
Encoding vs. Difficult-Short	.02	-.02	-.09
Memory vs. Easy-Short	.18	.16	.25
Memory vs. Difficult-Short	.34•	.34•	.50*
b) Peak Latency			
Encoding vs. Memory	.66†	.66†	.65†
Encoding vs. Easy-Short	-.02	-.02	-.02
Encoding vs. Difficult-Short	.26	.28	.26
Memory vs. Easy-Short	.11	.10	.10
Memory vs. Difficult-Short	.47*	.47*	.50*
c) Width			
Encoding vs. Memory	.03	.12	.12
Encoding vs. Easy-Short	-.03	-.05	-.06
Encoding vs. Difficult-Short	.05	-.06	-.12
Memory vs. Easy-Short	-.11	-.08	.03
Memory vs. Difficult-Short	.08	-.04	.01

Note: • $p < 0.1$, * $p < 0.01$, † $p < 0.0001$.

4. Discussion

The current study employed three separate tasks (encoding task, memory task, visual discrimination task) to investigate whether the LPN is a component linked to stimulus retrieval or rather to stimulus evaluation or response preparation processes. The LPN was present in all three tasks, with maximum amplitudes at occipital sites, which is in line with previous research (e.g., Cycowicz, et al., 2001; Friedman et al., 2005; Mecklinger et al., 2007). Importantly, the current findings suggest that the LPN is not a component linked to stimulus retrieval and response preparation, but rather to stimulus evaluation processes, which are modulated by task difficulty and stimulus complexity.

As expected, the results of the visual discrimination task indicated that the LPN amplitude is modulated by task difficulty, as greater LPN amplitudes were observed for difficult figures relative to easy figures, but only for short presentations. However, in contrast to expectations, the onset of the LPN did not vary as a function of the duration of stimulus presentation, suggesting that the LPN is not related to response preparation processes.

Subsequently, we compared the LPN for shortly presented easy and difficult figures of the visual discrimination task with the LPN of the encoding task and the memory task. As expected, the results indicate that the LPN amplitude is modulated by task difficulty, whereas the width and latency of the LPN are modulated by stimulus complexity. Specifically, as indicated by the behavioral performance data, the memory task was the most difficult task compared to the other tasks. This was reflected in a greater LPN amplitude in the memory task compared to the encoding task and visual discrimination task. Further, the encoding and memory task were associated with increased latency and width of the LPN relative to the visual discrimination task. In the encoding and memory task were utilized more complex emotional scenes than the geometrical figures of the visual discrimination task. Thus, we think that the observed differences regarding the width and latency of the LPN can be attributed to the higher level of stimulus complexity of the emotional images used in the encoding and memory task, which makes these figures more difficult to elaborate than geometrical ones. Hence, the use of geometrical figures in the visual discrimination task may have limited explanations of the present findings. Using the same stimuli across tasks would have excluded the possibility of stimuli differences as a confounding factor in the results. Nevertheless, we opted for different stimuli in the visual discrimination task for several reasons. First, using the same stimuli in the visual discrimination task, as in the encoding and memory task, would have likely led to transfer of stimulus-specific knowledge due to perceptual learning. Since the repeated exposure to the same set of stimuli would have affected the performance in the visual discrimination task, another set of stimuli was needed that is comparable in terms of stimulus complexity parameters. In an attempt to control for the parameters of stimulus complexity, we decided to use more difficult and complex geometrical figures together with more easy and less complex geometrical figures in the visual discrimination task. Second, the utilized stimuli in the encoding and memory task were complex emotional scenes. Emotional stimuli have been shown to modulate neurophysiological responses, they are associated with prolonged stimulus evaluation processes due to their complex nature (Olofsson, Nordin, Sequeira, & Polich, 2008), and they have been seen to engage the amygdala with functional consequences for various cognitive processes (Zald, 2003). To control for the possible influence of emotions and thus complex stimulus evaluation processes on LPN modulation, we employed non-emotional figures in the visual discrimination task.

It is important to note, however, that the aforementioned results did not differ between the short-term and long-term memory group. Since the results of the behavioral data indicate better memory performance in the STM group compared to the LTM group, one would expect that, if the LPN is modulated by task difficulty, this would be reflected by a greater LPN amplitude in the LTM group relative to the STM group. However, the analyses of the physiological data failed to reveal significant group differences. These lacking group differences are in line with previous reports showing no influence of time delay on the ERP old/new effect for emotional stimuli, even though the old/new discrimination, as indexed by the behavioral performance data, demonstrated reduced recognition over time (e.g., Wang, 2014; Weymar, Löw, & Hamm, 2011). The resilience of emotional memories over time is of course adaptive from an evolutionary perspective. In recent years, research has shown that STM and LTM share similar neural structures, such as the hippocampus, the medial temporal lobe (entorhinal cortex), and the parietal cortex (Jonides, Lewis, Nee, Lustig, Berman, & Moore, 2008), while they involve different molecular mechanisms (e.g., Izquierdo, Medina, Vianna, Izquierdo, & Barros, 1999). Collectively, these observations suggest that if the LPN is related to memory specific processes, the non-significant group differences may be the result of the utilized emotional stimuli and similar neural mechanisms underlying STM and LTM. Future research is needed that examines the influence of time delay (STM and LTM) on ERP correlates of recognition memory for non-emotional stimuli, to exclude the possibility that the non-significant group differences are due to the emotional content of the used material. Nevertheless, if the LPN, as hypothesized, reflects the reconstruction of the study episode in episodic memory (Mecklinger et al., 2016), one would expect differences in LPN indices between STM and LTM, such as amplitude, since the amount of information needed for the reconstruction and the specificity of memory search is likely to differ due to the mere passage of time. To the best of our knowledge, previous research has not examined the influence of time delay on the LPN in item and source memory tasks. The results of the current study suggest that time delay does not differentially influence the LPN in item memory tasks. Taken together, the non-significant group differences suggest that other factors than memory specific processes, in addition to task difficulty, contribute to the modulation of the LPN in episodic memory tasks.

The observation that the LPN is modulated by task difficulty is in line with other studies that reported greater LPN amplitude in high-load relative to low load conditions (Yang et al., 2015) and a greater LPN amplitude in source memory tasks compared to item memory tasks (Cycowicz et al., 2001; Friedman et al., 2005; Senkfor & Van Petten, 1998) as in these studies the performance was inferior in the source memory task relative to the item recognition task. Other studies failed to observe an association between LPN and task difficulty (Rosburg, Johansson, Weigl, & Mecklinger, 2015), as the LPN amplitude did not diminish after repeated testing. Behavioral data indicated a better performance after the second test but this has not been reflected in a reduced LPN amplitude. But since the second test took place immediately after the first test, and since the first test did not give any feedback to the participant with regard to their performance, it may be that the improvement in the behavioral performance is due to something else (e.g., adaptation) than actual memory performance. Unfortunately, the authors did not provide data with regard to response bias, for example, to further examine other possible explanations.

It may be argued that our results reflect differences in action monitoring processes across tasks, rather than differences in task difficulty. In previous studies, the involvement of action monitoring processes contributing to the LPN has been examined by confronting stimulus-locked and response-locked ERPs (e.g., Curran et al., 2007; de Chastelaine, Friedman, & Cycowicz, 2007; Herron, 2007; Nessler & Mecklinger, 2003). These studies reported a posterior response-locked error-related negativity, which influenced the stimulus-locked LPN. The error-related negativity is sensitive to error detection and error monitoring, and thus involved in action monitoring (Gehring, Goss, Coles, Meyer, & Donchin, 1993). We did not compute response-locked ERPs, as in our study the LPN occurred during the image presentation, several seconds before a response was made. Further, the LPN was even present in the encoding task in which the participants were required to make simple and subjective approach/avoidance decisions with regard to the presented stimulus material. This indicates that the LPN in the current study is not influenced by action monitoring processes.

The LPN in the current study as well as in previous research is often accompanied by a frontal positive slow wave. The functional significance of this positive slow wave is not understood. As it has been noted before, their reversed polarities and same onset mean that the modulation of one component may influence the absence or presence of the other component. This component overlap with the LPN thus makes a better understanding of the relationship between the LPN and the frontal slow wave difficult (Johansson & Mecklinger, 2003).Visual inspection of Figure 4 suggests that the frontal positive slow wave is modulated by stimulus type (geometrical figures vs. emotional images) and duration of stimulus presentation (short vs. long). Specifically, emotional images but not geometrical figures were associated with a pronounced accompanying positive slow wave. With respect to the visual discrimination task, the frontal positive slow wave emerged only under conditions of prolonged stimulus duration. Previous research suggests that perceptual and conceptual difficulty influence slow waves (posterior negative slow wave, frontal positive slow wave) due to high task demands (Ruchkin, Johnson, Mahaffey, & Sutton, 1988). That is, increased conceptual difficulty was associated with increased posterior slow wave scalp negativity and prefrontal slow wave positivity, while perceptual difficulty was associated with reduced posterior scalp negativity and prefrontal positivity. These results are in line with our observation that the LPN is modulated by task difficulty.

Overall, our results suggest that the LPN does not solely reflect memory related mechanisms. Since we observed the LPN in the encoding task and visual discrimination task with the same topographic distribution as in the memory task, this suggests that other processes than memory specific processes, such as general stimulus evaluation processes which are modulated by task difficulty, contribute to the functionality of the LPN. Nevertheless, the non-significant group differences (STM vs. LTM) with regard to the memory task imply that other factors, in addition to task difficulty, may contribute to the modulation of the LPN in episodic memory tasks. The similar LPN amplitudes across groups do however suggest that the LPN in episodic memory tasks is modulated by other factors than the amount of information needed for the reconstruction of the study episode, as it has been proposed by Mecklinger et al. (2016). Future research may benefit from studies with mild cognitive impaired participants to clarify the contribution of memory specific processes to the functionality of the LPN. The apparent contribution of multiple determinants in the modulation of the LPN argues for more research that examines the boundary conditions in the generation of the LPN in memory tasks, as well as in tasks without memory requirements, to gain a better understanding of the cognitive processes underlying the LPN.

Chapter 6

General Discussion

This thesis had two main objectives. First, we aimed to investigate attentional mechanisms in the visual perception of and memory for emotional events and to clarify the relative contribution of emotional valence and arousal. Second, we intended to examine the influence of individual differences in fear, anxiety, and approach systems on emotional attention and memory. Previous research regarding the automaticity of emotional influences on attention produced somewhat inconsistent results and electrocortical studies examining attentional mechanisms in the memory benefit for emotional events are lacking. In a series of experiments we addressed these objectives by examining controlled and automatic processes in emotional information processing and the respective influence of individual differences in trait emotionality.

1. Attentional Mechanisms Governing Emotional Effects on Cognition

Directing attention away from the emotional images resulted in reduced but enhanced attention to and memory for emotional images relative to neutral images (Chapters 3 and 4). These findings suggest that the emotional effects on cognition (i.e. attention and memory) are the result of automatic processes in emotional information processing. In Chapter 3 we provided evidence that emotional images are associated with increased attention - even when attention is directed away from the emotional stimulus. Specifically, exogenous attention is driven by the combined influence of valence and arousal properties of the stimulus with regard to the EPN, while attentional modulations on the LPP are influenced by the arousal value of the emotional stimulus. The emotional effects on the EPN were restricted to positive/high-arousal images. It is possible that the difference between negative and positive stimuli is the result of the erotic content of images that are part of the positive/high-arousal images (Schupp et al., 2008; Schupp et al., 2007b). Erotic images have been linked to less effortful categorization and recognition and thus enhanced encoding relative to negative images (Bradley, Hamby, Löw, & Lang, 2007). The difference between positive and negative images was absent for the LPP, which suggests that the valence effects on attentional biases are restricted to the early stages of selective processing. Further, behavioral data suggest that the emotional effects on the memory benefit for emotional events appear to occur rather automatic, independent of attentional resources (Chapter 4). Nevertheless, for the first time we provide electrophysiological evidence showing that attentional manipulations at encoding exert a different influence on recollection based recognition between negative and positive images. Recollection of positive/high-arousal images requires a more effortful search for the memory trace, while negative images are recollected less effortful, even when attentional resources at encoding are limited. This observation is in line with the proposition that especially negative stimuli are processed on a preattentive, automatic level (Christianson, 1992), resulting in enhanced memory performance, while positive stimuli may require deeper elaboration and maintenance processing. Thus, even though positive/high-arousal images are associated with enhanced allocation of attentional resources under conditions of high perceptual load in the early stages of information processing, the emotional effects on memory for positive/high-arousal images seem to be the result of controlled elaboration processes rather than automatic processes. Automatic attentional biases for positive/high-arousal images thus do not automatically translate into automatic influences underlying the memory benefit for positive/high-arousal images. Finally, in Chapter 5 we demonstrated that the LPN is modulated by attentional mechanisms rather than by memory specific processes as has been proposed by Mecklinger et al. (2016). Instead of being modulated by the amount of information needed for the reconstruction of the study episode, we put forward that the LPN reflects controlled stimulus evaluation processes that are partially modulated by task difficulty.

1.1 The contribution of emotional arousal on attentional effects in cognition

In Chapters 2, 3, and 4 we examined valence-arousal interactions in the emotional effects on attention and memory. The results show that arousing stimuli are associated with enhanced affective evaluations, increased attention, and better memory performance than low-arousing emotional stimuli. In Chapter 3 we showed that attentional biases associated with emotional stimuli occur rather automatic, but only for high-arousal emotional images. Emotional attention towards low-arousal emotional images requires available attentional resources. This effect was especially prominent for the LPP that is associated with enhanced attention towards and increased perceptual processing of emotional relative to neutral stimuli (for reviews see Olofsson et al., 2008; Schupp et al., 2006). These results are in line with the notion that emotional arousing stimuli are linked to prioritized processing and that they capture attention more readily than neutral stimuli (e.g., Öhman et al., 2001;

Vuilleumier et al., 2001) and they support previous findings, which suggested that attentional biases are driven by the arousal dimension of the stimulus (Buodo et al., 2002; Schimmack, 2005; Vogt et al., 2008). However, manipulating the attentional resources did not differentially affect the memory benefit for low-arousal and high-arousal emotional stimuli (Chapter 4). This finding is in contrast with the proposition that the memory benefit for arousing emotional stimuli is driven by automatic processes, whereas the memory benefit for low-arousing emotional stimuli is driven by controlled and conscious encoding strategies (Kensinger, 2004). This view has been supported by previous findings showing that attentional manipulations abolished the memory benefit for low-arousing emotional stimuli (Clark-Foos & Marsh, 2008; Kensinger & Corkin, 2004). We assume that this discrepancy is due to modality differences in which the concurrent task was presented. We presented the concurrent task in the visual modality, while the aforementioned studies presented the concurrent task in the auditory modality. Research has shown that when the attention task taps the auditory modality, instead of the visual modality, perceptual load does not differentially impact the emotional effects on attentional processes (Schupp et al., 2008). In accordance, another study that manipulated attentional resources by using a concurrent task that tapped the visual modality, found that attentional manipulations did not alter the enhanced memory performance for medium and low arousal negative images relative to neutral images (Pottage & Schaefer, 2012). Therefore, it is possible that modality-specific attentional processes play a role in the memory benefit for low-arousing emotional stimuli. All in all, low-arousal stimuli are not processed automatically and therefore exert their influence on the allocation of attention via controlled encoding processes. Although low-arousal negative and positive stimuli were equally affected by attentional manipulations during visual perception, attentional manipulations did not impair the memory benefit for negative/low-arousal images relative to positive/low-arousal images. This suggests that negative stimuli, based on their evolutionary significance, are recollected less effortful than positive images, even when attention at encoding and regardless of arousal level.

1.2 The impact of individual differences in fear, anxiety, and approach systems

Individual differences in the RST systems (BAS, FFFS, BIS) modulate controlled processes in emotional information processing (Chapter 2), they differentially impact exogenous attention to emotional stimuli (Chapter 3), and they influence memory performance for emotional events (Chapter 4). In Chapter 2 we provided evidence for differential trait congruency effects between stimuli (words vs. images) with regard to valence and arousal ratings and memory performance for emotional stimuli. More importantly, individual differences in goal-drive persistence moderated the relationship between valence ratings and memory performance for affective images, while arousal ratings associated with negative/high-arousal words mediated the influence of individual differences in reward reactivity on subsequent memory performance. The results demonstrate that by examining trait processes underlying trait-congruency effects in emotional information processing one is able to gain valuable insight into how differences in personality gives rise to these trait-congruency effects. A better understanding of trait processes will provide information regarding trait structures and a better understanding of the biological basis of personality traits (Hampson, 2012). Exogenous attentional mechanisms to emotional stimuli were influenced by individual differences in the fear and impulsivity dimension (Chapter 3). As indexed by the EPN, heightened levels of fear were related to decreased interference by and thus increased active avoidance of negative distractor images and to reduced interference by the distractor images when attention was focused on negative target words. These results correspond to the punishment sensitivity and active avoidance of the source of danger, respectively, associated with the FFFS (e.g., Gray & McNaughton, 2000; McNaughton & Corr, 2004, 2008). As indexed by the LPP, increased levels of impulsivity were associated with reduced interferences by low-arousal emotional images and with reduced interference by the distractor images when attention was focused on positive target words. Since impulsivity is assumed to be related to regulatory control over motivated behavior (Depue & Collins, 1999), the reduced interference by low-arousal emotional stimuli is likely the result of increased regulatory control in high impulsive individuals, while the enhanced attention to positive targets words reflects the overall increased sensitivity towards positive stimuli (e.g., Gray, 1970; Gray & McNaughton, 2000) and the need for rash actions associated with the impulsivity facet of reward sensitivity (Carver, 2005). Overall, these results emphasize the importance to differentiate fear from anxiety and reward components from impulsivity (e.g., Corr & Cooper, 2016; Gray & McNaughton, 2000; McNaughton & Corr, 2004, 2008). Lastly, in Chpater 4 we showed that the inverted ERP old/new effects associated with positive/high-arousal images presented during limited attention trials mediated the influence of reward reactivity on subsequent recognition performance. Elevated levels of reward reactivity were associated with impaired reflection in response to positive/high-arousal stimuli that were presented under condition of high perceptual load. This disinhibited behavior then resulted in impaired recognition performance, which is in line with the proposal that dysfunctional reward reactivity governs disinhibited behavior (Gorenstein & Newman, 1980. In addition, the behavioral data indicated that higher BIS levels are associated with better memory for neutral and low-arousal images in the STM group, especially for images presented under conditions of divided attention. This observation is likely the result of enhanced attention associated with the activation of the BIS (e.g., Gray & McNaughton, 2000; McNaughton, & Corr, 2004).

In general, our results in Chapters 2, 3, and 4 provide support for the notion that the BAS is multidimensional and that BAS behavior comprises a cascade of BAS processes (Carver & White, 1994; Corr, 2008; Corr & Cooper, 2016; De Pascalis et al., 2017). Nevertheless, more studies are needed that examine individual differences in BAS components in emotional information processing tasks. In this way one will gain a better understanding of the multidimensional nature of reward sensitivity. This is especially important since the different BAS components have been found to be related to to differential cortical activations representing distinct, but interacting, neurobiological systems (De Pascalis et al., 2017) that work adjunctively to move towards the reinforcer (Carver & White, 1994; Corr, 2008). Chapters 2 and 3 further present support for the view that negative stimuli can elicit approach behaviors and that approach motivation can result in the experience of negative affect and distress (e.g., Harmon-Jones et al., 2013). However, the relationship between approach motivation and information processing associated with negative stimuli was present only when controlled elaboration processes were available and not when attentional resources were manipulated. This suggests that attentional resources are required to activate approach behavior in response to negative stimuli. We further demonstrated that the FFFS is related to information processing of negative stimuli, but not the BIS (Chapters 2 and 3). This observation provides support for the revised RST and for a two-dimensional model of defense that separates fear from anxiety (e.g., Gray & McNaughton, 2000; McNaughton & Corr, 2004, 2008) by showing that when stimuli elicit no conflict (e.g., simultaneous activation of the BAS and FFFS), they elicit defensive behaviors, such as active avoidance, for instance. Since trait anxiety has been related to increased interference by distractors in frontal brain regions associated with cognitive control (Bishop, 2009; Bishop et al., 2007), it is possible that the BIS modulates attentional mechanisms in emotional information processing rather via frontal, top-down controlled mechanisms. In concordance, the behavioral data in Chapter 4 indicated that the increase in attention associated with the BIS (e.g., Gray & McNaughton, 2000; McNaughton, & Corr, 2004) is positively related to memory for low-arousal emotional stimuli presented under conditions of high perceptual load. Lastly, in Chapters 2, 3, and 4 we showed that the observed individual differences in trait emotionality vary with the valence and arousal value of the emotional stimulus, with some trait-congruency effects only being observed for low-arousal emotional stimuli and others being restricted to emotional stimuli high in arousal. Future studies should therefore manipulate the valence and arousal value of the stimulus more frequently to obtain a clearer picture regarding the influence of personality trait differences on valence-arousal interactions in emotional information processing. In conclusion, individual differences in the fear, anxiety, and approach systems modulate automatic and controlled processes in emotional information processing.

2. Clinical Implications

Affective disorders, such as anxiety, depression, and posttraumatic stress disorder, are characterized by attentional biases (e.g., Gotlib et al., 2004; MacLeod et al., 1986) and memory biases (e.g., Coles & Heimberg, 2002; Watkins et al., 1992) for negative and threatening information, and by increased susceptibility to emotional distraction (e.g., MacNamara & Hajcak, 2010; Schweizer & Dalgleish, 2011; Wang et al., 2008). In the current thesis we demonstrated an attentional bias for (positive) arousing stimuli relative to low-arousal and neutral stimuli - even when attentional resources are limited (Chapter 3) - and that memory biases for negative stimuli reflect automatic processes in information processing, while memory biases for positive stimuli seem to depend on controlled encoding and retrieval processes (Chapter 4). The results are in line with previous reports showing that attentional resources mediate the memory benefit for positive stimuli, but not for negative stimuli (Talmi et al., 2007). Applying interventions to regulate dysfunctional recollection of traumatic memories will not necessarily abolish these biases, but they can help in regulating affective experiences associated with those memories, reducing the impact of emotions on cognitive functions.

Elevated levels and continuous activation of the RST systems (FFFS, BIS, BAS) have been shown to be involved in psychopathology (e.g., Bijttebier et al., 2009; Pickering, & Gray, 1999). Individual differences in these underlying neurobiological systems are related to differences in cognitive control in order to prevent interference by emotional distractors (Chapters 3 and 4), showing that increased activations of the RST systems are associated with dysfunctional emotion-attention interactions in sensory information processing. Thus, our results provide insight into the underlying mechanisms through which individual differences in trait emotionality put individuals with elevated activity in the RST systems at risk for dysfunctional attentional and memory biases and thus increasing the chances for the development of affective disorders (Bijttebier et al., 2009).

3. Concluding Remarks

In conclusion, emotions influence sensory information processing via automatic, bottom-up mechanisms and via controlled, top-down processes. Understanding the mechanisms through which emotions exert their influence on cognition will help to gain a better understanding of affective disorders that are characterized by dysfunctional emotional information processing. Therefore, a better understanding of attentional mechanisms in emotional information processing will be helpful in the development of interventions that can be useful in the regulation of attention and dysfunctional memory formation.

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Summary

There is an on-going debate in the literature concerning the contribution of automatic and controlled processes underlying emotional effects on cognition. The current thesis had two objectives: (1) to investigate attentional mechanisms in the visual perception of and memory for emotional events and (2) to examine the influence of individual differences in fear, anxiety, and approach systems on emotional attention and memory.

In Chapter 2 we demonstrate trait-congruency effects in emotional information processing across a range of cognitive domains. More importantly, we show that by examining trait processes underlying trait-congruency effects in emotional information processing one is able to gain valuable insight into how differences in personality traits gives rise to these trait-congruency effects.

In Chapter 3 we reveal that early stage of exogenous attention to emotional stimuli are modulated by the valence-arousal interactions of the emotional stimulus, while later stages of exogenous attention appear to be driven by the arousal value of the stimulus. More importantly, individual differences in the fear system and impulsivity dimension influenced attentional biases for emotional stimuli, underlining the importance to differentiate fear from anxiety and reward components from impulsivity.

In Chapter 4 we show that divided attention at encoding does not further modulate the influence of affective content on recognition memory performance, but electrophysiological results provide evidence that this is due to different underlying mechanisms. Specifically, electrophysiological results suggest that visual attentional processes play a role in the recollection based recognition of positive/high-arousal images, but not of negative images. Thus, recollection of positive/high-arousal images requires a more effortful search for the memory trace, while negative images, regardless of arousal value, are recollected less effortful, even when attention at encoding is limited. This effect mediated the negative relationship between reward reactivity and recognition performance for positive/high-arousal images presented under conditions of high perceptual load, indicating that dysfunctional reward reactivity is related to disinhibited behavior.

In Chapter 5 we provide evidence that the late posterior negativity is modulated by attentional mechanisms rather than by memory specific processes. That is, instead of being modulated by the amount of information needed for the reconstruction of the study episode, we put forward that this electrocortical component reflects controlled stimulus evaluation processes that are, at least in part, modulated by task difficulty.

Overall, the results of the present thesis show that emotions exert their influence on sensory information processing via automatic, bottom-up mechanisms and via controlled, top-down processes. Further, elevated activation of fear, anxiety, and approach systems are associated with dysfunctional emotion-attention interactions in sensory information processing. Clarifying the contribution of attentional mechanisms in emotional information processing will help to gain a better understanding of affective disorders characterized by attentional and memory biases, which is necessary for the development of interventions that can be useful in the regulation of dysfunctional attention allocation and memory formation.

Publications

De Pascalis, V., **Sommer, K.,** & Scacchia, P. (in preparation). Extraversion, impulsivity, and behavioural approach in the stimulus analysis and motor response initiation.

Sommer, K., & De Pascalis, V. (in preparation). Neurophysiological correlates underlying the influence of divided attention on the emotional memory enhancement effect.

Sommer, K., & De Pascalis, V. (in preparation). The role of fear and impulsivity in exogenous attention to emotional stimuli as indexed by the early posterior negativity and late positive potential.

Sommer, K., & De Pascalis, V. (submitted). Personality, affective evaluations, and emotional memory: Comparing Eysenck's and Gray's theory in relation to emotional information processing.

Sommer, K., Vita, S., & De Pascalis, V. (under revision). The late posterior negativity in episodic memory: A correlate of stimulus retrieval?

Sommer, K., Van der Molen, M. W., & De Pascalis, V. (2016). BIS/BAS sensitivity and emotional modulation in a prepulse inhibition paradigm: A brain potential study. *Physiology & Behavior, 154,* 100-113.