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Neural mechanisms underlying the integration of emotion and working memory

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ABSTRACT

The present study aimed at investigating the behavioral effects and neuronal correlates of emotional content and emotional components, i.e. valence and arousal, in the context of a verbal working memory task. Our findings in twenty healthy male subjects demonstrate that (1) word valence has no impact on performance in the verbal working memory task, and (2) that emotion leads to an increase of activation in cognition-related lateral prefrontal regions, whereas cognitive effort yields enhanced deactivation in emotion-related cortical midline regions. The stronger dorsolateral prefrontal recruitment during emotional stimuli may reflect an arousal effect or higher cognitive effort due to interference with emotion.

Introduction

There are numerous experiences in our everyday life showing that information and situations associated with emotions are better remembered. While an emotional enhancement effect on episodic memory performance has been shown in several studies at the behavioral as well as at the neural level (Buchanan and Adolphs, 2003; Kensinger and Corkin, 2003; Smith et al., 2005), less is known about the relation between emotion and working memory (WM).

WM is an essential component of many cognitive operations, from complex decision making to selective attention (Baddeley, 1986). One commonly utilized WM task is the *n-back* task, which requires participants to monitor a series of stimuli and to respond whenever a stimulus is presented that is the same as the one presented *n* trials previously. The task requires subjects to continually adjust the information held in working memory, to incorporate the most recently presented stimulus while simultaneously rejecting or ignoring more temporally distant stimuli. N-back tasks have been used to demonstrate that the dorsolateral prefrontal cortex (DLPFC) is implicated in numerous cognitive functions relevant to WM, including holding to-be-remembered information online (Goldman-Rakic, 1994; Jonides et al., 1993), monitoring and manipulating the to-be-remembered information (Petrides, 1994), response selection (Rowe et al., 2000), and implementation of strategies to facilitate memory (Bor et al., 2003, 2004). Activity in the anterior cingulate cortex (ACC) during n-back tasks is often described in relation to increased effort, complexity, or attention (Botvinick et al., 2004; Duncan and Owen, 2000). While the exact role of the ACC is still debated, most theories suggest a role in cognitive control, including error detection, conflict monitoring, and/or task switching (Botvinick et al., 2004; Carter and van Veen, 2007; Hyafil et al., 2009).

Previous emotion and WM research has found that while emotional state, mood, or context influences working memory (Aoki et al., 2011; Erk et al., 2007; Gray et al., 2002), the use of emotional stimuli has no consistent impact on working memory performance. For example, Kensinger and Corkin (2003) examined how the emotional content of stimuli influenced working memory performance across different tasks. They found no influence of emotion on accuracy, but slower reaction times for negative compared to neutral stimuli in a nonverbal working memory task. A recent study by Becerril and Barch (2011) supports these findings to some extent by showing higher accuracy but slower reaction times for negative compared to neutral nonverbal stimuli. Other studies using emotional stimuli reported no impact whatsoever on WM performance (Döhnel et al., 2008; Perlstein et al., 2002). Regarding the question whether emotional content affects processes supporting working memory, Perlstein et al. (2002) found evidence that emotional content reduced working memory related brain activation in right DLPFC. This result would suggest that emotional content might hinder performance on working memory tasks. Two recent fMRI studies however reported either no effect of emotional content on DLPFC activity (Döhnel et al., 2008) or increased DLPFC activity during an emotional WM task (Neta and Whalen, 2011).

It is also still unclear how working memory performance and associated brain activation is mediated by the properties of an emotional stimulus. One dimensional approach to emotion emphasizes the contribution of two orthogonal components, namely arousal and valence (Lang et al., 1999; Russell, 1980). Arousal refers to how strongly an emotion is

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experienced on a continuum that varies from calm to excitement. Valence refers to the subjective experience of the affective value or quality of an emotional stimulus independent of its sensory quality on a continuum that varies from positive to negative with neutral in the middle (Bradley and Lang, 1994). Imaging studies demonstrated that arousal and valence differ not only psychologically, but also in their neural substrates (Anderson et al., 2003; Dolcos et al., 2004; Grimm et al., 2006; Viinikainen et al., 2010). Arousal has been linked to neural activity in the amygdala as well as in the dorsomedial prefrontal cortex (DMPFC) (Anders et al., 2004; Dolcos et al., 2004; Grimm et al., 2006). Valence has been associated with neural activity in the medial prefrontal cortex (ventromedial prefronal cortex and pregenual anterior cingulate; VMPFC/PACC) and the lateral prefrontal cortex including the ventrolateral (VLPFC) and dorsolateral (DLPFC) prefrontal cortex (Dolcos et al., 2004; Grimm et al., 2006). The valence hypothesis states that the left prefrontal cortex is dominant in the processing of positive emotions, whereas the right prefrontal cortex is dominant in the processing of negative emotions (Davidson and Irwin, 1999). There is some evidence for valence related specificity in the medial prefrontal cortex (George et al., 1995; Paradiso et al., 1999) during approach or appetitive tasks, supporting the role of this region in appetitive or reward circuits (Rolls, 2000; Wager et al., 2003). On the other hand numerous studies described medial prefrontal involvement in processing emotional stimuli irrespective of valence (see review by Phan et al., 2002), therefore suggesting that its involvement could be attributed to its role in the processing of arousal. Only few studies have investigated the effects of valence and arousal on working memory performance using fMRI and reported conflicting results: While Perlstein et al. (2002) found reduced activation in the right DLPFC during negative stimuli, Döhnel et al. (2008) report no valence- or arousal specific effects in the prefrontal cortex. Conversely, Becerril and Barch (2011) used a nonverbal *2-back* task and found greater activation in the left DLPFC during negative and in the medial prefrontal cortex during positive stimuli. All these studies used nonverbal stimuli to investigate the effect of emotional content on WM performance and associated neural activity which raises the question how the interaction between emotional content, WM performance and associated neural activity might be influenced during a verbal WM task. Previous studies found domain related specificity with increased left prefrontal activity during verbal and increased right prefrontal activity during non-verbal WM tasks (Smith and Jonides, 1999; Smith et al., 1996).

The aim of the present study was to investigate the behavioral and neural effects of emotional content and emotional components, i.e. valence and arousal, in the context of a verbal working memory task. We employed a *2-back* task with standardized emotional words from the Berlin Affective Word List (BAWL; Võ et al., 2009) and incorporated positive, negative and neutral words matched according to different arousal levels in order to elucidate valence and arousal effects. The experiment was conducted with respect to the following questions: (i) Is verbal working memory influenced by emotion and is this effect valence- or arousal dependent? (ii) How does the integration of emotion and WM processes affect brain activity in emotion-related (medial PFC) and WM-related (DLPFC) regions? (iii) Is WM associated brain activity differentially dependent on arousal or valence? (iv) Are there any lateralization effects due to domain and/or valence specificity?

Methods

Subjects

Twenty healthy male subjects (age 23.5 ± 2.4; range 18–28 years; IQ 106.7 ± 6.7) were recruited through advertisements. Somatic as well as psychiatric health status was evaluated by a structured psychiatric interview (Mini-International Neuropsychiatric Interview) (Sheehan et al., 1998) performed by a psychologist. No subject had to be excluded due to fulfilling the criteria for an axis I or axis II disorder according to DSM-IV criteria, diagnosed neurological and general medical disorders or clinically relevant abnormalities. Mood and arousal before and after the experiment were measured by means of the Multidimensional Mood Questionnaire (MDBF; Steyer et al., 1997). Intelligence was assessed using a word recognition test (WST; Schmidt and Metzler, 1992), which is functionally equivalent to the widely used NART test (Nelson and O'Connell, 1978). All subjects were right-handed as assessed with the Edinburgh Handedness Inventory (Oldfield, 1971). The study was carried out in accordance with the latest version of the Declaration of Helsinki and approved by the Institutional Review Board of the Charité University Medicine (Berlin, Germany). All subjects gave written informed consent before screening.

Experimental design

Emotional stimuli were German nouns taken from the Berlin Affective Word List (BAWL; Võ et al., 2009). According to the BAWL norms, the emotional words were classified as positive, negative and neutral (35 different words per condition). The words of the three valence conditions were matched for word length (5–8 letters), imageability and frequency (total frequency of appearance per million words). The emotional arousal was equivalent in the positive and negative conditions. The stimuli were consecutively presented within a *2-back* working memory task (Fig. 1), which provides a novel means of studying the interface between verbal working memory and emotion. Subjects were required to monitor a series of words and to respond whenever a word was presented that was the same as the one presented 2 trials previously. Subjects performed a practice run prior to the experiment followed by 15 blocks of experimental trials. Each block consisted of 15 words of either positive, negative or neutral valence presented for 500 ms with an interstimulus interval (ISI) of 1500 ms and was followed by a fixation trial (10–14 s). During the experiment 75 words per condition were presented. The condition order was randomized across the task. Stimuli were generated by Presentation® (Neurobehavioral Systems, Inc., Albany, CA, USA) and presented via video goggles (VisuaStim digital). Participants responded by pushing a fiber-optic light sensitive key press.

After the fMRI session participants rated all emotional words presented during the task on a 7-point scale regarding emotional valence (−1 = very negative/3 = very positive) and on a 5-point scale regarding emotional arousal (1 = not arousing/5 = very arousing) according to the BAWL norms.

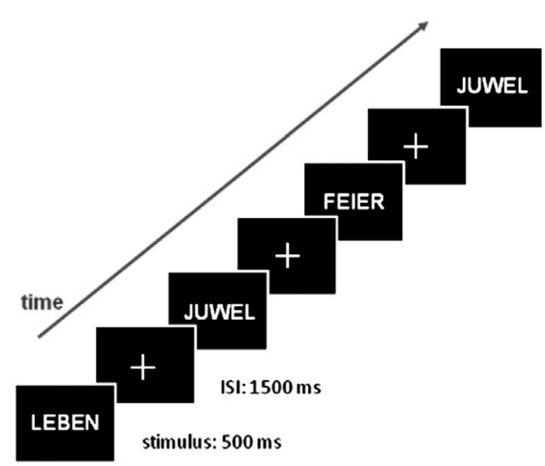

Fig. 1. Experimental Paradigm. Schematic representation of the *n-back* task. Word stimuli of either positive, negative or neutral valence presented for 500 ms with an interstimulus interval (ISI) of 1500 ms and followed by a fixation trial (10–14 s).