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Emotional valence and arousal affect reading in an interactive way: Neuroimaging evidence for an approach-withdrawal framework

Francesca M.M. Citron[a,*], Marcus A. Gray[b,c], Hugo D. Critchley[c,d,e], Brendan S. Weekes[f], Evelyn C. Ferstl[g]

[a] Cluster of Excellence "Languages of Emotion", Freie Universität Berlin, Habelschwerdter Allee 45, D-14195 Berlin, Germany
[b] Centre for Advanced Imaging, The University of Queensland, Australia
[c] Psychiatry, Brighton & Sussex Medical School, Universities of Brighton and Sussex, UK
[d] Sussex Partnership NHS Foundation Trust, Brighton, UK
[e] Sackler Centre for Consciousness Science, University of Sussex, UK
[f] Laboratory for Communication Science, The University of Hong Kong, China
[g] Center for Cognitive Science, Albert-Ludwigs-Universität Freiburg, Germany

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ABSTRACT

A growing body of literature shows that the emotional content of verbal material affects reading, wherein emotional words are given processing priority compared to neutral words. Human emotions can be conceptualised within a two-dimensional model comprised of emotional valence and arousal (intensity). These variables are at least in part distinct, but recent studies report interactive effects during implicit emotion processing and relate these to stimulus-evoked approach-withdrawal tendencies.

The aim of the present study was to explore how valence and arousal interact at the neural level, during implicit emotion word processing. The emotional attributes of written word stimuli were orthogonally manipulated based on behavioural ratings from a corpus of emotion words. Stimuli were presented during an fMRI experiment while 16 participants performed a lexical decision task, which did not require explicit evaluation of a word's emotional content.

Results showed greater neural activation within right insular cortex in response to stimuli evoking conflicting approach-withdrawal tendencies (i.e., positive high-arousal and negative low-arousal words) compared to stimuli evoking congruent approach vs. withdrawal tendencies (i.e., positive low-arousal and negative high-arousal words). Further, a significant cluster of activation in the left extra-striate cortex was found in response to emotional than neutral words, suggesting enhanced perceptual processing of emotionally salient stimuli.

These findings support an interactive two-dimensional approach to the study of emotion word recognition and suggest that the integration of valence and arousal dimensions recruits a brain region associated with interoception, emotional awareness and sympathetic functions.

1. Introduction

A growing body of literature shows that the emotional content of verbal material affects reading (Citron, 2012; Kissler, Assadollahi, & Herbert, 2006). In particular, emotionally-laden words are processed faster and more accurately than neutral words (Kousta, Vinson, & Vigliocco, 2009; Larsen, Mercer, & Balota, 2006), they elicit larger amplitudes of electrophysiological components associated with emotion processing (Kissler, Herbert, Peyk, & Junghofer, 2007), and they yield enhanced BOLD responses in limbic brain regions (Kuchinke et al. 2005).

Several theoretical models of emotion have been proposed, including amongst others, models which propose a small number of universal underlying emotional states, i.e., discrete emotions such as joy, fear, etc. (see Levenson, 2011 for a review), appraisal models, which suggest that specific emotions are importantly influenced by appraisal processes which integrate the situational context of an event (see Ellsworth & Scherer, 2003), and dimensional models, which may be particularly useful for investigating the emotional processing of language.

Dimensional models suggest that emotion is best understood as occurring within a dimensional space, most commonly a two-dimensional space spanning valence and arousal. Emotional valence describes the extent to which an emotion is positive or negative, whereas arousal refers to its intensity, i.e., the strength of the associated emotional state (Feldman Barrett & Russell, 1999; Lang,

* Corresponding author. Tel.: +49 30 838 57869.
E-mail address: fmm.citron@gmail.com (F.M.M. Citron).

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Bradley, & Cuthbert, 1997; Russell, 2003). These models typically assume valence and arousal to be at least in part distinct dimensions (Feldman Barrett & Russell, 1999; Reisenzein, 1994). However, behavioural ratings of emotion word stimuli show that highly positive and highly negative stimuli tend to be more arousing (Bradley & Lang, 1999) and negative stimuli are generally rated higher in arousal than positive stimuli (e.g., Citron, Weekes, & Ferstl, 2012).

Support for a distinction between these two dimensions comes from neuroimaging studies that demonstrate dissociable cortical representations during processing of odours, tastes, and written words. Specifically, the orbitofrontal and ventral anterior cingulate cortices respond more to valence, whereas the amygdala and anterior insular cortex respond more to arousal (Colibazzi et al., 2010; Lewis, Critchley, Rotshtein, & Dolan, 2007; Posner et al., 2009; Small et al., 2003; Winston, Gottfried, Kilner, & Dolan, 2005).

Despite this evidence, some empirical work shows that valence and arousal affect processing of emotional stimuli in an interactive way (Robinson, Storbeck, Meier, & Kirkeby, 2004). The authors propose a model according to which stimuli with negative valence (e.g., bitter taste) or with high arousal (e.g., a loud noise) elicit a withdrawal tendency and corresponding mental set, because they represent a possible threat; in contrast, stimuli with positive valence (e.g., sweets) or with low arousal (e.g., a newsletter) elicit an approach tendency because they are perceived as safe. According to this account, these two tendencies are initiated independently at a pre-attentive level and subsequently integrated in order to evaluate the stimulus for further action (Robinson et al., 2004). Thus, positive low-arousal and negative high-arousal stimuli will be easier to process because they elicit congruent tendencies (approach and withdrawal, respectively), whereas positive high-arousal and negative low-arousal stimuli will be more difficult to process because they elicit conflicting approach-withdrawal tendencies. According to this model, these opposite tendencies are integrated at an implicit processing level, before explicit stimulus evaluation.

In a series of experiments, Robinson et al. (2004) asked participants to judge the emotional valence (positive vs. negative) of pictures as well as written words. The results showed consistent interactive effects of valence and arousal, whereby reaction times (RTs) were faster for stimuli eliciting congruent approach or withdrawal tendencies compared to stimuli eliciting conflicting tendencies (Robinson et al., 2004). In these studies, participants were asked to explicitly evaluate the emotional connotation of the stimuli. Thus, it is difficult to tease apart whether the interactive effects of valence and arousal are caused by truly automatic processes, i.e., implicit integration of approach-withdrawal tendencies, or instead by intentional stimulus evaluation as well as strategic processes.

To this end, Eder and Rothermund (2010) devised a task to assess the emotional evaluations of pictorial stimuli indirectly and observed the same interaction reported by Robinson et al. (2004). Further support for implicit interactive effects of valence and arousal during reading of emotionally-laden words comes from studies using a lexical decision task (LDT), i.e., decide whether a letter string is a real word or a not. This task allows assessment of the implicit processing of a word′s emotional connotation (Bayer, Sommer, & Schacht, 2012; Citron, Weekes, & Ferstl, under review; Hofmann, Kuchinke, Tamm, Võ, & Jacobs, 2009; Larsen, Mercer, Balota, & Strube, 2008). Slower LD latencies are reported for words eliciting conflicting approach-withdrawal tendencies compared to words eliciting congruent tendencies.

Neural evidence for interactive effects of valence and arousal comes from studies showing modulation of the amplitude of emotion-related event-related potential (ERP) components during the implicit processing of emotional pictures (Feng et al., 2012) as well as words (Citron, Weekes, & Ferstl, 2013; Hofmann et al., 2009) (but see Bayer et al., 2012 for distinct ERP effects of the two emotional dimensions).

The aim of the present study is to test for interactive effects of valence and arousal on regional neural activity, in order to identify which brain regions are responsible for the implicit integration of approach-withdrawal tendencies during reading of emotionally-laden words. This is the first hemodynamic neuroimaging study to explore the interaction rather than the dissociation of emotional dimensions. In fact, previous functional magnetic resonance imaging (fMRI) studies have tested for the dissociation of brain activation between valence and arousal dimensions and employed either tasks requiring explicit and deep processing of a word′s emotional content (Colibazzi et al., 2010; Posner et al., 2009) or self-referential processing, which tends to evoke a bias toward "yes" responses to positively valenced words, which possibly enhances the processing of these trials (Lewis et al., 2007). Such studies support the multidimensional account of emotion processing, but do not speak to the interrelationship between valence and arousal during implicit emotion processing in reading.

Typically, the reading of emotionally-laden words in studies requiring implicit processing of their emotional content evokes activity within a set of brain regions that include the amygdala (Herbert et al., 2009; Kensinger & Schacter, 2006; Lewis et al., 2007; Straube, Sauer, & Miltner, 2011), the anterior cingulate cortex (ACC; Kuchinke et al., 2005; Lewis et al., 2007), the insula (Lewis et al., 2007; Straube et al., 2011), the prefrontal cortex (PFC; Compton et al., 2003; Kuchinke et al., 2005; Straube et al., 2011), more specifically the orbito-frontal cortex (OFC; Kuchinke et al., 2005; Lewis et al., 2007), the hippocampus, the parahippocampal gyrus (Kuchinke et al., 2005) and extra-striate cortical areas (Compton et al., 2003; Herbert et al., 2009).

In an event-related fMRI design, we presented participants with written positive and negative words, high or low in arousal, and neutral words. Stimuli were intermixed with non-words and participants performed a LDT, thus evoking implicit emotion processing. According to Robinson et al.′s model and the extant supportive empirical evidence, we predicted slower LD latencies, lower accuracy and enhanced BOLD signal response for words eliciting conflicting approach-withdrawal tendencies (i.e., positive high-arousal and negative low-arousal words) compared to words eliciting congruent tendencies (i.e., positive low-arousal and negative high-arousal words). More specifically, we expected enhanced BOLD responses in the insula and/or ACC. In fact, the former subserves affective/interoceptive awareness, i.e., integration of bodily sensations and cognitive, evaluative processes (Brooks, Zambreanu, Godinez, Craig, & Tracey, 2005; Craig, 2009; Critchley, Wiens, Rotshtein, Ohman, & Dolan, 2004), whereas the latter is associated with error detection (Botvinick, Nystrom, Fissell, Cater, & Cohen, 1999) and conflict processing (Kanske & Kotz, 2011; Ullsperger, Harsay, Wessel, & Ridderinkhof, 2010). Further, both insula and ACC show activation when the task requires a minimum degree of processing depth (as required by the LDT) (Phan, Wager, Taylor, & Liberzon, 2002). We also more generally predicted better performance and enhanced activation of emotion-related brain regions in response to emotionally-laden words compared to neutral words. Further, we predicted faster LD latencies, higher accuracy and enhanced activation of the classical lexico-semantic neural network in response to words compared to non-words (cf. Fiebach, Friederici, Mueller, & von Cramon, 2002; Price, 2012).

2. Method

2.1. Participants

Nineteen native British English-speakers from the University of Sussex (10 women, 9 men), aged between 18 and 37 years (mean ± SD=23.7 ± 5.6 years) took part in the experiment. They were all right-handed with normal or corrected-to-normal vision, had no learning disabilities and took no medication for mood