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Temporospatial analysis of explicit and implicit processing of negative content during word comprehension

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ABSTRACT

Although divergences between explicit and implicit processing of affective content during word comprehension have been reported, the underlying nature of those differences remains in dispute. Prior studies focused on either the timing or the spatial location of the effects. The present study examined the precise dynamics of the processing of negative words when attention is directed to affective content or to non-emotional properties by capitalizing on fine temporal resolution of the event-related potentials (ERPs) and recent advances in source localization. Tasks were used that required accessing knowledge about different semantic properties of negative and neutral words. In the direct task, participants' attention was directed towards emotional information. By contrast, subjects had to decide whether the words' referent could be touched or not in the indirect task. Regardless of being processed explicitly or implicitly, negative compared to neutral words were associated with more errors and greater key pressure responses. Electrophysiologically, affective processing was reflected in larger amplitudes to negative words in a late positive component (LPC) at the scalp level, and in increased activity in the pre-supplementary motor area (pre-SMA) at the voxel level. Interestingly, an interaction between emotion and type of task was observed. Negative words were associated with more errors, larger anterior distributed LPC amplitudes and increased activity in the posterior cingulate cortex (PCC) in the direct compared to the indirect task. This LPC effect was modulated by the concreteness of the words. Finally, a task effect was found in a posterior negativity around 220 ms, with enhanced amplitudes to words in the direct compared to the indirect task. The present results suggest that negative information contained in written language is processed irrespective of controlled attention is directed to it or not, but that this processing is reinforced in the former case.

1. Introduction

Emotional stimuli, including language, may be processed either in a relatively automatic and unintentional implicit manner or in a deliberated and controlled explicit fashion (Greenwald & Banaji, 1995; Pessoa, 2005). Thus, an important research question has to do with the modulation of brain activity by the task-dependent attentional focus of participants. The present study was concerned with the Event-related potential (ERP) correlates, the underlying neural sources, as well as the behavioral effects that are involved in explicit and implicit processing of negative information during word comprehension.

Given their precise temporal resolution, the timing of brain mechanisms underlying the processing of emotional words has been extensively examined using scalp-recorded ERPs. In those studies that used direct or explicit tasks, participants' attention was directed towards the emotional connotations of the words. Alternatively, subjects' attention was distracted from the affective content of the words in studies that used indirect or implicit tasks. Regardless of the occasional finding of modulations in the P1, N1, P2 or N400 components (e.g., Bernat, Bunce, & Shevrin, 2001; Herbert, Kissler, Junghofer, Peyk, & Rockstroh, 2006; Hofmann, Kuchinke, Tamm, Vo, & Jacobs, 2009; Kanske & Kotz, 2007; Trauer, Andersen, Kotz, & Müller, 2012), effects have been mainly observed in two waves. The first component is an early posterior negativity (EPN) to emotional compared to neutral words that has been interpreted to index enhanced sensory encoding resulting from reflex-like visual attention to affective information (Herbert, Junghofer, &

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Kissler, 2008; Kissler, Herbert, Peyk, & Junghofer, 2007; Rellecke, Palazova, Sommer, & Schacht, 2011). This effect has been observed in indirect tasks such as lexical decision (Bayer, Sommer, & Schacht, 2012a; Palazova, Mantwill, Sommer, & Schacht, 2011; Schacht & Sommer, 2009a, 2009b; Scott, O'Donnell, Leuthold, & Sereno, 2009) or word counting (Kissler, Herbert, Winkler, & Junghofer, 2009), as well as in explicit affective categorization tasks (Frühholz, Jellinghaus, & Herrmann, 2011). However, other studies failed to report EPN effects with both indirect (Carretié et al., 2008; Hinojosa, Carretié, Valcárcel, Méndez-Bértolo, & Pozo, 2009; Hinojosa, Méndez-Bértolo, & Pozo, 2010; Hofmann et al., 2009; Kanske & Kotz, 2007; Méndez-Bértolo, Pozo, & Hinojosa, 2011a; Rellecke et al., 2011) and direct tasks (Naumann, Bartussek, Diedrich, & Laufer, 1992; Schapkin, Gusev, & Kuhl, 2000). Emotional words are also associated with an enhancement of a LPC in both indirect (Carretié et al., 2008; Hinojosa et al., 2010; Hofmann et al., 2009; Kanske & Kotz, 2007; Kissler et al., 2009; Méndez-Bértolo et al., 2011a; Schacht & Sommer, 2009a, 2009b) and direct tasks (Frühholz et al., 2011; Naumann, Maier, Diedrich, Becker, & Bartussek, 1996; Naumann et al., 1992; Schapkin et al., 2000), which presumably reflects higher order stimulus evaluation (Bayer, Sommer, & Schacht, 2012b; Herbert et al., 2006; Kissler et al., 2009).

The findings on the timing of emotional processing during word comprehension (*when* affective processing occurs) have been complemented by data on its anatomical substrates (*where* affective processing occurs). The results of several functional magnetic resonance imaging (fMRI) studies with both direct (Cunningham, Raye, & Johnson, 2004; Maddock, Garrett, & Buonocore, 2003; Straube, Sauer, & Miltner, 2011) and indirect (Kensinger & Schacter, 2006; Kuchinke et al., 2005; Whalen et al., 1998) tasks indicate that the processing of emotional content in words is subserved by a brain network distributed across multiple cortical and subcortical areas. These regions include prefrontal cortices (ventromedial and ventrolateral), the insula, the pre-SMA, the anterior and posterior cingulate cortex, as well as the amygdala.

Finally, at the behavioral level some studies have found a processing advantage for emotional over neutral words, which is associated with faster responses and more accurate responses in both direct and indirect tasks (e.g., Schacht & Sommer, 2009a, 2009b). Others have shown that relative to neutral words the processing of emotional words elicited slower reaction times and lower accuracy (e.g., Algom, Chajut, & Ley, 2004; Bayer et al., 2012a; Carretié et al., 2008; Estes & Verges, 2008; Hofmann, Kuchinke, Tamm, Vo, & Jacobs, 2009). Interestingly, it has been also found that emotional words and pictures prepare people to display forceful actions (Aarts, Custers, & Marien, 2008; Coombes, Cauraugh, & Janelle, 2006; Coombes, Corcos, Pavuluri, & Vaillancourt, 2012).

Only a limited number of the aforementioned studies directly compared tasks that required explicit versus implicit processing of affective properties of words. In a series of studies Naumann and collaborators (1992, 1996) explored the processing of neutral, positive and negative adjectives in emotional judgments and structural tasks, in which participants indicated if a particular word was shorter, equal, or longer than six letters. The LPC showed either different topographies (Naumann et al., 1992) or enhanced amplitude (Naumann et al., 1996) for direct compared to indirect tasks, which led the authors to establish that explicit affective processing is more intense. Recently, Frühholz and collaborators (2011) compared the processing of negative and neutral words and faces in color naming and affective categorization tasks and found that negative words elicited larger EPN amplitudes in the explicit than in the implicit task. Emotion also modulated the amplitude of the LPC, although its amplitude was not sensitive to the direct versus indirect nature of the task. Also, behaviorally, subjects took longer and were less accurate to categorize words in an affective dimension than to name their colors. None of these effects were modulated by the emotional content of the words. In an fMRI study, Straube and collaborators (2011) explored the processing of positive, negative and neutral words when participants made valence and grammatical class judgments. Regardless of task, the processing of emotional words led to increased activation in the ventromedial prefrontal cortex and the amygdala. Task effects were found that indicated that the processing of emotional words in the direct compared to the indirect task led to enhanced activation in the dorsomedial prefrontal cortex and the anterior cingulate cortex. Finally, in another fMRI study Cunninghan and collaborators (2004) asked their participants to perform explicit (good-bad) and implicit evaluations (abstract-concrete) about socially relevant concepts. Amygdala activation was observed in both explicit and implicit tasks. In contrast, the explicit emotional categorization was selectively associated with increased activity in ACC, lateral areas of the prefrontal cortex and the frontal pole.

It is important to note that prior studies have focused almost exclusively on either the temporal course (when) or the anatomical substrates (where) of implicitly and explicitly processed emotional words. A further step would be to examine the ERP components that may be potentially reflecting the processing of negative words when attention is directed to affective content or to non-emotional properties, and thereafter to identify the brain regions that selectively subserve such effects. The current study was conceived to address this issue by exploiting the high temporal resolution of the ERPs and recent advances in source localization. Furthermore, in an attempt to specifically isolate the effect of attention to emotional content of words and minimize confounding factors we designed direct and indirect tasks that demanded some degree of meaning-based evaluation.

According to some theoretical proposals, word meaning is comprised of a number of semantic features that are organized in networks in which knowledge about these properties is distributed (Kissler, Assadollahi, & Herbert, 2006; Patterson, Nestor, & Rogers, 2007; Pulvermüller, 1999). There is general agreement to consider emotional significance as one of these properties (Kissler et al., 2006; Schacht & Sommer, 2009b). Another source of semantic knowledge comes from the information about the concreteness of the concept denoted by a word, which is also assumed to be stored in semantic networks (Kellenbach, Wijers, & Mulder, 2000; Reilly & Kean, 2007). Thus, in the direct task participants had to decide whether a word was negative or neutral. Alternatively, participants judged if a particular word referent could be touched or not in the indirect task.

Predictions may be outlined as follows. At the scalp level, the processing of negative words was expected to be associated with enhanced amplitudes of the LPC and/or the EPN (Frühholz et al., 2011; Kissler et al., 2009; Schacht & Sommer, 2009a, 2009b). At a neuroanatomic level, increased activity in the prefrontal (e.g., ventro-lateral and/or dorsolateral regions) and/or cingulate cortices was predicted (Cunningham et al., 2004; Maddock et al., 2003; Straube et al., 2011). Behaviorally, previous studies have shown that the processing of emotional compared to neutral words is associated with longer RTs/lower accuracy for emotional words (Bayer et al., 2012a; Hofmann, Kuchinke, Tamm, Vo, and Jacobs, 2009), whereas shorter RTs/higher accuracy were reported in others (Schacht & Sommer, 2009a, 2009b). As already noted above, the processing of emotional stimuli has been also associated to motor facilitation responses (Aarts et al., 2008; Coombes et al., 2006; Coombes et al., 2012). Thus, we measured the force generated by participants when they pressed response keys, a parameter that has not previously investigated in prior research contrasting explicit and implicit processing of negative words. Increased for production was expected for negative compared to neutral words.

In order to test these hypotheses, a two-step approach analysis was devised to analyze data. First, temporospatial principal