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Research report

Auditory attention enhances processing of positive and negative words in inferior and superior prefrontal cortex

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ABSTRACT

Visually presented emotional words are processed preferentially and effects of emotional content are similar to those of explicit attention deployment in that both amplify visual processing. However, auditory processing of emotional words is less well characterized and interactions between emotional content and task-induced attention have not been fully understood. Here, we investigate auditory processing of emotional words, focussing on how auditory attention to positive and negative words impacts their cerebral processing.

A Functional magnetic resonance imaging (fMRI) study manipulating word valence and attention allocation was performed. Participants heard negative, positive and neutral words to which they either listened passively or attended by counting negative or positive words, respectively. Regardless of valence, active processing compared to passive listening increased activity in primary auditory cortex, left intraparietal sulcus, and right superior frontal gyrus (SFG). The attended valence elicited stronger activity in left inferior frontal gyrus (IFG) and left SFG, in line with these regions' role in semantic retrieval and evaluative processing. No evidence for valence-specific attentional modulation in auditory regions or distinct valence-specific regional activations (i.e., negative > positive or positive > negative) was obtained.

Thus, allocation of auditory attention to positive and negative words can substantially increase their processing in higher-order language and evaluative brain areas without modulating early stages of auditory processing. Inferior and superior frontal brain structures mediate interactions between emotional content, attention, and working memory when prosodically neutral speech is processed.

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1. Introduction

During spontaneous visual processing, when participants can allocate attentional resources freely to the stimuli presented, emotional stimuli are prioritized over neutral stimuli (e.g., Schupp, Junghöfer, Weike, & Hamm, 2003; Schupp et al., 2007). As the neural signature of this prioritized processing of emotional stimuli parallels effects of feature-based attention (Schupp, Flaisch, Stockburger, & Junghöfer, 2006), the preferential processing of emotional material is sometimes also referred to as "motivated attention" (Lang, Bradley, & Cuthbert, 1992). Selective processing of emotional stimuli is assumed to be biologically prepared, promoting survival via enhanced resource allocation and natural selective attention to intrinsically relevant stimuli (Bradley, Keil, & Lang, 2012).

However, the attention-grabbing properties of emotional stimuli also extend to emotionally arousing words whose emotional significance is ontogenetically learnt. Across several electrophysiology studies, preferential visual processing of emotionally arousing words (e.g., Herbert, Junghofer, & Kissler, 2008; Keuper et al., 2014; Kissler, Herbert, Peyk, & Junghofer, 2007; Kissler & Herbert, 2013; Trauer, Andersen, Kotz, & Müller, 2012, Trauer, Kotz, & Müller, 2015) has been found in similar time windows as during free viewing of emotional pictures (Junghöfer et al., 2001; Schupp et al., 2007), faces (Schupp et al., 2004), or gestures (Flaisch et al., 2015).

Functional magnetic resonance imaging (FMRI) studies likewise established enhanced haemodynamic activity for emotionally arousing compared to neutral words, both during passive processing (e.g., Herbert et al., 2009) and under specific task requirements such as lexical (Kuchinke et al., 2005; Nakic, Smith, Busis, Vythilingam, & Blair, 2006) or semantic decisions (e.g., Jackson & Crosson, 2006). During reading, emphasizing stimulus-driven processing, enhanced activation in extrastriate visual areas and limbic regions like the amygdala were found (Herbert et al., 2009). In contrast, during task-specific processing of emotion words such as semantic monitoring or lexical decisions, activations in prefrontal cortex and middle temporal gyrus (MTG), predominantly in the left hemisphere, have been reported (Cato et al., 2004; Jackson & Crosson, 2006; Kuchinke et al., 2005; Nakic et al., 2006).

Thus, for different, primarily visual stimuli, preferential processing of emotional content has been demonstrated, but a key question is how this bottom-up stimulus-driven processing of emotional material interacts with goal-driven top-down allocation of attention. In vision, the allocation of attention to stimulus features such as shape, colour or location in space has been shown to enhance activity in feature-specific extrastriate visual cortex regions (e.g., Corbetta, Miezin, Dobmeyer, Shulman, & Petersen, 1991, 1990; Schoenfeld, Hopf, Merkel, Heinze, & Hillyard, 2014). These effects are at least partly orchestrated by prefrontal brain structures (Corbetta & Shulman, 2002). EEG studies show that feature-based attention to emotional pictures (e.g., Ferrari, Codispoti, Cardinale, & Bradley, 2008; Schupp et al., 2007) as well as written words (Schindler & Kissler, 2016) amplifies their processing over visual cortex at distinct processing stages.

FMRI studies further demonstrated that attention to emotional faces increases activity in the right superior temporal sulcus (STS) (Narumoto, Okada, Sadato, Fukui, & Yonekura, 2001), which, as part of the core face processing system, is particularly involved in processing emotional facial expressions (Haxby, Hoffman, & Gobbini, 2000). This supports the notion that emotion and attention interact to amplify processing in stimulus-specific brain regions, although not all processing stages seem to be equally amplified by attention to emotion: For instance in Narumoto et al.'s (2001) study, fusiform areas exhibited face selectivity but no interactive effect of attention to emotion. Less research addressed auditory processing, but during passive listening auditory cortex has also been found to exhibit larger responses to emotional complex environmental sounds than to neutral ones (Plichta et al., 2011).

Spatial attention during dichotic listening amplifies contra-lateral auditory cortex responses (e.g., Jäncke, Buchanan, Lutz, & Shah, 2001). Auditory spatial attention to emotional (angry) prosody has been found to activate orbitofrontal and parietal brain regions. At the same time, attention-independent processing enhancement for angry prosody has been identified in regions of the auditory cortex such as the right middle STS as well as the right amygdala (Sander et al., 2005). Similarly, angry prosody has been found to evoke larger responses in right middle STS, irrespective of spatial attention (Grandjean et al., 2005) or whether the listener's task is focussed on semantic meaning or emotional prosody (Ethofer, Anders, Erb et al., 2006).

Overall, previous research into the relationship between emotion and attention suggests that emotional stimuli can be processed both along attention-dependent and attention-independent neural pathways whereby attention-dependent mechanisms appear to be orchestrated primarily via frontal cortical networks and operate on sensory processing.

However, so far, little is known about the functional neuroanatomy underlying auditory processing of emotional language content and its modulation by attentional demands. Extant studies mostly used EEG and focused on the visual modality: Electrophysiology studies showed preferential visual processing of emotional words to persist in spite of a distracting task (Kissler, Herbert, Winkler, & Junghofer, 2009), suggesting independent pathways. On the other hand, cuing attention to negative words facilitates processing at an early lexical (P2) and a late semantic integration (N400) processing stage (Kanske, Plitschka, & Kotz, 2011). Generally, attention to word content has been shown to reduce the semantic N400 component, indicating that pre-activation by attention facilitates semantic integration (Cristescu & Nobre, 2008). Recently, visual attention to word valence has been shown to result in parallel effects of emotion and attention on early ERPs, but interactive effects on late ERPs: the sources of these effects were localized in frontal and visual brain areas, with interactive effects localized in visual cortex (Schindler & Kissler, 2016). In the fMRI, visual cueing of attention to semantic word categories has been shown to activate language-related areas such as the left inferior frontal and left posterior temporal gyri (Cristescu, Devlin, & Nobre, 2006). So far, however, it is unclear how attention and emotional content interact in