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Non-conscious word processing in a mirror-masking paradigm causing attentional distraction: An ERP-study

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ABSTRACT

In this event-related potential (ERP) study a masking technique that prevents conscious perception of words and non-words through attentional distraction was used to reveal the temporal dynamics of word processing under non-conscious and conscious conditions. In the non-conscious condition, ERP responses differed between masked words and non-words from 112 to 160 ms after stimulus-onset over posterior brain areas. The early onset of the word–non-word differences was compatible with previous studies that reported non-conscious access to orthographic information within this time period. Moreover, source localisations provided evidence for automatic activation of prelexical phonological information, whereas no evidence for non-conscious semantic processing was found. When subjects were informed about the masking technique, lexical differences occurred at later time intervals, suggesting conscious access to additional word related information. These results indicate that early visual word processing does not depend entirely on attentional resources, but that non-conscious processing probably is restricted to rather lower-level linguistic information.

1. Introduction

One of the most controversial issues in cognitive psychology research addresses the extent to which non-consciously perceived linguistic information is cognitively processed and therefore can influence human behaviour (Kouider & Dehaene, 2007). To elucidate this issue, it is important to know what brain structures and functions are differentially activated during conscious and non-conscious linguistic stimulus processing. The following event-related potential (ERP) study relates to both of these issues.

Although models of conscious visual word processing vary in many aspects, there is evidence from various ERP studies suggesting that skilled word reading is based on hierarchically organised processing steps, engaging an anatomically distributed neural system, whereby subsequently specific types of information becomes available (Cohen & Dehaene, 2009; Coltheart, Curtis, Atkins, & Haller, 1993; Fiez & Petersen, 1998; Warrington & Shallice, 1980). Processing starts with an analysis of physical surface characteristics of words such as visual contrast, luminance, curves and lines that constitute single letters. Several studies have related this processing stage with an early electrophysiological activation between 50 and 150 ms after stimulus-onset over bilateral occipital regions (called P1 visual component), reflecting neuronal processing in striate and extra striate visual areas (Cornelissen, Tarkiainen, Helenius, & Salmelin, 2003; Dale et al., 2000; Khateb, Pegna,

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Michel, Landis, & Annoni, 2002; Sereno & Rayner, 2003). Next, various prelexical processes develop. At these stages, single letters are identified at abstract representation levels, information about letter position is analysed and automatic extraction of invariant orthographic regularities from alphabetic stimuli is initiated (Grossi & Coch, 2005). These prelexical stages of processing are electrophysiologically reflected by a negative activation mainly over left occipito-temporal scalp regions between 150 and 200 ms, referred to as linguistic N150 component (e.g., Cornelissen et al., 2003; Schendan, Ganis, & Kutas, 1998; Spironelli & Angrilli, 2007). Other studies demonstrated that alphabetic and non-alphabetic stimuli (words, legal and illegal non-words vs. faces or objects) elicit distinguishable N150 responses (Bentin, Mouchetant-Rostain, Giard, Echallier, & Pernier, 1999; Cornelissen et al., 2003; Nobre, Allison, & McCarthy, 1994; Pammer & et al., 2004), and there is also evidence for an early orthographic sensitivity in the N150 response (e.g., Hauk, Davis, Ford, Pulvermüller, & Marslen-Wilson, 2006). At the next processing stage, whole visual word forms are accessed. This lexical stage is characterised by an electrophysiological activity between 200 and 250 ms after stimulus-onset mainly over left-lateralised inferior temporal regions (Cohen et al., 2000; Pammer et al., 2004; Proverbio, Cok, & Zani, 2002), reflecting activation in the left mid fusiform gyrus, the so-called visual word form area (VWFA; Cohen et al., 2000; although VWFA is also engaged in prelexical orthographic processing, see Schurz et al., 2010). Several previous studies suggest that lexical processing is followed by phonological processing, that entails access to lexical phonological representations occurring slightly after the activation of orthographic representations, i.e., starting at around 300 ms after stimulus-onset over central and temporal areas (Bentin et al., 1999; Carreiras, Perea, Vergara, & Pollatsek, 2009; Grainger, Kiyonaga, & Holcomb, 2006; Simon, Bernard, Largy, Lalonde, & Rebai, 2004). The last stage in visual word processing involves the activation of semantic representations and is associated with ERP modulations around 400 ms after stimulus-onset over central electrode sites (Holcomb, 1993; Kiefer & Spitzer, 2000; Kutas & Hillyard, 1980; Proverbio, Vecchi, & Zani, 2004; Van Petten, 1993).

In sum, in this sequential view of word processing it is assumed that analysis of whole visual word forms under conscious conditions is completed at around 200–250 ms after stimulus-onset, reflected by electrophysiological activity over posterior electrode sites. This posterior activity precedes more anterior activity characterising processing of phonologic and semantic information. However, it is important to note that results from some ERP studies on the time course and the functional relationship of the various processes during reading are not without controversy. For example, in contrast to the strictly sequential and modular accounts some ERP studies provide evidence that the speed of processing under conscious conditions might be substantial faster than has traditionally been proposed (Foxe & Simpson, 2002; Thorpe et al., 1996), possibly leading to automatic and parallel access to orthographic, phonological and even semantic information already within 150 ms (e.g., Braun, Hutzler, Ziegler, Dambacher, & Jacobs, 2009; Pulvermüller, Assadollahi, & Elbert, 2001; Sereno, Brewer, & O'Donnell, 2003). Moreover, such immediate and parallel access to linguistic information has been shown not only in visual, but also in spoken language processing and has been referred to as immediacy principle (e.g., Hagoort, 2008).

With respect to non-conscious processing, research over the last three decades using temporal masking paradigms (i.e., very short stimulus presentation combined with preceding and/or following visual pattern masks) and paradigms controlling attention in a way that prevents awareness of information that is visible in principle has demonstrated non-conscious cognitive processing of visually presented linguistic as well as non-linguistic stimuli, but the literature on how far processing under such conditions extends is still inconclusive. Previous behavioural and neurophysiological research suggests that visual information can become non-consciously available at various processing levels, including perceptual (e.g., Dehaene et al., 2001), orthographic (Dehaene et al., 2001; Fairhall, Hamm, & Kirk, 2007; Grossi & Coch, 2005), phonological (Brysbaert, 2001; Carreiras et al., 2009; Ferrand & Grainger, 1992; Humphreys, Evett, & Taylor, 1982; Luo, Johnson, & Gallo, 1998), morphological (Rastle, Davis, Marslen-Wilson, & Tyler, 2000) and even semantic processing stages (e.g., Dehaene et al., 1998; Devlin, Jamison, Matthews, & Gonnerman, 2004; Greenwald, Draine, & Abrams, 1996; Kiefer, 2002; Kiefer & Spitzer, 2000; Mack & Rock, 1998; Marcel, 1983; Rolke, Heil, Streb, & Henninghausen, 2001). Nevertheless, while most studies showed non-conscious perceptual and orthographical processing, previous results are still inconsistent not only concerning the phonological level (e.g., Kouider, Dehaene, Jobert, & Le Bihan, 2007), but particularly the semantic level, and some studies convincingly postulated non-semantic interpretations of these latter effects (Abrams & Greenwald, 2000; Damian, 2001; Eckstein & Perrig, 2007).

Aside from the above mentioned debate about the depth of non-conscious word processing, only few neuropsychological studies directly compared the temporal dynamics or localisation of brain activation during conscious and non-conscious word processing. These studies showed mixed results. While some studies report comparable patterns of brain activation (e.g., Kiefer & Spitzer, 2000), others support the view that cognitive processes under conscious and non-conscious conditions are qualitatively separable. For example, Fecteau, Kingstone, and Enns (2004) demonstrated that during non-conscious word reading, right hemispheric brain structures are much more involved compared to conscious word reading. Concerning the time course of brain activation, a recent ERP study by Fairhall et al. (2007) showed non-conscious word–non-word differences that occurred substantially faster than under conscious conditions, suggesting distinct signatures of non-conscious word reading.

Whereas most studies on non-conscious word processing use temporal masking techniques, Perrig and Eckstein (2005) employed a spatial mirror-masking technique that prevents conscious perception of letter strings through attentional distraction processes. Masked word and non-word primes used by Perrig and Eckstein consisted of non-descending letters that were mirrored at their baseline. An example of a mirror-masked word can be seen in Fig. 1. This kind of spatial masking results in unfamiliar, nonsense geometric like figures, in which words are no more identifiable as long as they are not expected, i.e., when subjects are not informed about the mirror-masking technique. Therefore it is assumed that mirror-masking causes a state of inattentional blindness.