Brain & Language 126 (2013) 217–229

Contents lists available at SciVerse ScienceDirect

Brain & Language

journal homepage: www.elsevier.com/locate/b&l

Multiple routes for compound word processing in the brain: Evidence from EEG ☆

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ARTICLE INFO

Article history:
Accepted 5 April 2013

Keywords:
Compounds
Dual-route
Speech
Language
ERPs
MMN

ABSTRACT

Are compound words represented as unitary lexical units, or as individual constituents that are processed combinatorially? We investigated the neuro-cognitive processing of compounds using EEG and a passive-listening oddball design in which lexical access and combinatorial processing elicit dissociating Mismatch Negativity (MMN) brain-response patterns. MMN amplitude varied with compound frequency and semantic transparency (the clarity of the relationship between compound and constituent meanings). Opaque compounds elicited an enhanced 'lexical' MMN, reflecting stronger lexical representations, to high- vs. low-frequency compounds. Transparent compounds showed no frequency effect, nor differed to pseudo-compounds, reflecting the combination of a reduced 'syntactic' MMN indexing combinatorial links, and an enhanced 'lexical' MMN for real-word compounds compared to pseudo-compounds. We argue that transparent compounds are processed combinatorially alongside parallel lexical access of the whole-form representation, but whole-form access is the dominant mechanism for opaque compounds, particularly those of high-frequency. Results support a flexible dual-route account of compound processing.

1. Introduction

The representation and processing of compound words, and morphologically complex words more generally, remains a controversial topic in psycholinguistics. Are compound words represented and processed as unitary lexical units as proposed by full-listing models (Bybee, 1995), or only as individual constituents that are analysed via a combinatorial mechanism as proposed by full-parsing models (Libben, Derwing, & de Almeida, 1999; Taft, 2004; Taft & Forster, 1976)? Alternatively, both mechanisms may be invoked as suggested by dual-route models (Baayen, Dijkstra, & Schreuder, 1997; Isel, Gunter, & Friederici, 2003; Koester, Gunter, & Wagner, 2007; Koester, Gunter, Wagner, & Friederici, 2004; Koester, Holle, & Gunter, 2009; Sandra, 1990; Zwitserlood, 1994). One feature that may affect representation and processing is semantic transparency, the clarity of the relationship between the meaning of the compound and that of its constituents. The meaning of fully transparent compound words (e.g. *homework*, *workman*) can be understood from the combination of the meanings of their individual constituents (*home* + *work*, *work* + *man*). Therefore, in principle, transparent compounds do not require a distinct lexical representation but may be processed via a mechanism akin to syntactic rules linking words in sentences. By contrast, the meaning of opaque compounds cannot be derived from their constituents (e.g. *framework*, *strawman*) and thus may require dedicated whole-form lexical storage. A second potentially important factor is that of the overall lexical frequency: more frequent words are more likely to benefit from readily available whole-form storage (which, in turn, may be more likely to develop as a result of frequent use), whereas less frequently used compounds might have to be processed through a combinatorial mechanism. Here we investigate the representation and processing of spoken compound words using a passive-listening oddball paradigm. By capitalising on the existence of different patterns of Mismatch Negativity (MMN) amplitudes depending on whether the link between first and second constituents is lexical or syntactic, we ask whether hearing the second constituent of a semantic or transparent compound triggers access to a whole compound representation or combinatorial processing. Before describing our experimental approach in more detail, we review the existing data on compound processing.

To explore whether the meanings of individual constituents are accessed during compound word processing, a number of behavioural studies used a semantic priming paradigm. It was shown

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http://dx.doi.org/10.1016/j.bandl.2013.04.002

that, for transparent but not opaque compounds, lexical decision times to two-constituent[1] compound words were speeded up by a preceding prime that was semantically related to either the first or second constituent of the target compound word (Sandra, 1990; Zwitserlood, 1994). From this it was argued that individual constituent semantics were accessed only for transparent compounds, suggesting the possibility of combinatorial processing only for transparent compounds, but a direct whole-form access route for opaque compounds. Further evidence for access to constituent meanings of transparent but not opaque compounds comes from a cross-modal priming study in which visually presented transparent compound words were primed by the prior auditory presentation of both first and second compound constituents and vice versa, but no such effects were observed for opaque compounds (Zhou & Marslen-Wilson, 2000). In line with these findings, another cross-modal semantic priming study showed that the first constituents of German spoken compounds primed visually presented targets only when the second constituent was transparent, but not when it was opaque, suggesting that activation of both constituents is dependent on the transparency of the second constituent (Isel et al., 2003).

Access to compound constituents has also been studied neurophysiologically, using event-related potentials (ERPs). Here, the evidence for activation of constituent semantics is mixed. In one study using a cross-modal semantic priming paradigm the amplitude of the N400 electrophysiological brain response to spoken English compounds was modulated by the relatedness of preceding pictures to either of the compound constituents. This finding indicates activation of both constituents (Pratarelli, 1995), although reaction times did not show semantic priming effects. Notably, however, this study did not control for transparency, which does not allow us to conclude whether or not the observed effects occur for different subtypes of compounds.

Despite the widespread use of the semantic priming paradigm, it has been argued (Koester et al., 2007) that, on their own, semantic priming effects between constituents and compounds are not conclusive evidence for combinatorial processing, because they could be driven by pure semantic relatedness; the lack of semantic priming for opaque compounds could simply reflect the unrelatedness between the meaning of the compound and its constituents rather than the absence of an attempt at combinatorial parsing. If, instead, evidence for morphological decomposition could be found, it would lend stronger support to a combinatorial mechanism.

Indeed, a number of studies have explored morphological decomposition using behavioural psycholinguistic techniques. In a lexical decision task using a repetition priming paradigm, it was shown that the presentation of either the first or second constituent as a lexical prime speeded up lexical decisions for both opaque and transparent compounds indicating constituent access for each type (Libben, Gibson, Yoon, & Sandra, 2003). This finding fits well with an earlier study showing that both opaque and transparent compounds primed lexical decision times to both first and second constituents (Zwitserlood, 1994). Decomposition has also been investigated by manipulating lexical frequencies, capitalising on the well-established lexical frequency effect observed in various paradigms in which recognition times are faster for higher-frequency lexical items. In these studies, frequency effects of both the first and second constituents were found on lexical decision times to English compounds (Andrews, 1986), although in one study the effect was greater for the second constituent (Juhasz, Starr, Inhoff, & Placke, 2003), and in a study on Spanish and Basque only the frequency of the second constituent had an effect on lexical decision times (Duñabeitia, 2007). Also in support of individual constituent access is evidence that response times to reject pseudo-compounds in a lexical decision task were longer when the individual constituents were real words (Andrews, 1986; Taft & Forster, 1976).

Other studies exploring morphological decomposition have measured eye movements during reading, which, as a continuous behavioural measure, have the potential to reveal more about the time course of lexical processing than response times alone. First-constituent frequency has been repeatedly shown to have a rapid but lasting effect on eye movements as judged by an effect on first fixation and gaze durations, whereas second constituent frequency is usually important later affecting gaze duration (Andrews, Miller, & Rayner, 2004; Hyönä & Pollatsek, 1998; Juhasz et al., 2003; Pollatsek, Hyönä, & Bertram, 2000). Although suggestive of access to both constituents, these studies notably used only transparent compounds, making it impossible to judge whether constituent access may also take place for non-transparent cases. In those few studies that have explicitly compared processing of transparent and opaque compounds (frequencies of constituents and whole-word forms were matched between the two types), no differences were obtained on any eye movement measure for either English (Frisson, Niswander-Klement, & Pollatsek, 2008) or Finnish (Pollatsek & Hyönä, 2005) stimuli, from which it was argued that morphological decomposition occurs for both types. However, in contrast to the above eye tracking findings other research has failed to show an impact of constituent frequency on lexical decision times in Dutch, but did observe whole-word frequency effects (Van Jaarsveld & Rattink, 1988), argued to reflect the absence of morphosyntactic decomposition but access to a full representation instead. Similarly, a study conducted in Chinese, this time in the auditory domain, showed that the frequency of the whole word rather than constituents could be the dominant factor affecting lexical decision times to semantically transparent compound words, which also supports access to a full-word representation (Zhou & Marslen-Wilson, 1994).

Several studies provide neurophysiological evidence for morphological decomposition. In an EEG study exploring the processing of both opaque and transparent spoken compounds, syntactic gender disagreements between the determiner and both constituents elicited a left anterior negativity (LAN) for both compound types, supporting morphological decomposition in each case (Koester et al., 2004). In a more recent study, transparent compound words were presented visually in the context of a lexical decision task whilst MEG was recorded (Fiorentino & Poeppel, 2007). Reaction times to correctly identified words were faster for compound than monomorphemic words, and even faster for those that had a high lexical frequency. The results were interpreted as reflecting access to constituents, which facilitated whole-compound processing. Analysis of the MEG data focused on the latency of the M350, a component which had previously been shown to be sensitive to lexical variables (Embick, Hackl, Schaeffer, Kelepir, & Marantz, 2001; Pylkkanen, Stringfellow, & Marantz, 2002). In line with the behavioural results, the M350 peak occurred earlier for compounds relative to monomorphemic controls, which was argued to reflect the facilitatory effect of accessing individual morpheme constituents on access to the full compound word representation.

Two recent studies attempted to measure the combinatorial process itself, using the N400 brain response as an index of lexico-semantic integration of compound constituents. Transparent compounds elicited a larger N400 than opaque compounds suggesting processing via a combinatorial mechanism (Koester et al., 2007). Focusing only on transparent compounds, a larger N400 was found for the plausible second constituents, reflecting greater integration difficulty that started even before the end of the final

[1] Although compounds may have multiple constituents, 2-constutuent compounds are most common in the majority of European languages and therefore most often used in investigations.