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Research report

Neural dynamics of inflectional and derivational morphology processing in the human brain

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ABSTRACT

We investigated neural distinctions between inflectional and derivational morphology and their interaction with lexical frequency using the mismatch negativity (MMN), an established neurophysiological index of experience-dependent linguistic memory traces and automatic syntactic processing. We presented our electroencephalography (EEG) study participants with derived and inflected words of variable lexical frequencies against their monomorphemic base forms in a passive oddball paradigm, along with acoustically matched pseudowords. Sensor space and distributed source modelling results showed that at 100–150 msec after the suffix onset, derived words elicited larger responses than inflected words. Furthermore, real derived words showed advantage over pseudo-derivations and frequent derivations elicited larger activation than less frequent ones. This pattern of results is fully in line with previous research that explained lexical MMN enhancement by an activation of strongly connected word-specific long-term memory circuits, and thus suggests stronger lexicalisation for frequently used complex words. At the same time, a strikingly different pattern was found for inflectional forms: higher response amplitude for pseudo-inflections than for real inflected words, with no clear frequency effects. This is fully in line with previous MMN results on combinatorial processing of (morpho)syntactic stimuli: higher response to ungrammatical morpheme strings than grammatical ones, which does not depend on the string's surface frequency. This pattern suggests that, for inflectional forms, combinatorial processing route dominates over whole-form storage and access. In sum, our results suggest that derivations are more likely to form unitary representations than inflections which are likely to be processed combinatorially, and imply at least partially distinct brain mechanisms for the processing and representation of these two types of morphology. These dynamic mechanisms, underpinned by perisylvian networks, are activated rapidly, at 100–150 msec after the information arrives at the input, and in a largely automatic fashion, possibly providing neural basis for the first-pass morphological processing of spoken words.

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1. Introduction

Many words in a language are complex in that they have more than one meaningful element, so-called morpheme, e.g., *boy* + *s* (*boy* + plural marker) or *boy* + *ish* (*boy* + attenuator). Words such as 'boys' are called inflections, in which the '-s' specifies mainly a grammatical role, whereas words like 'boyish' are called derivations, i.e., new forms, as a marker like '-ish' changes both syntactic category (from noun to adjective) and meaning. It is still unclear, however, how complex words are represented and processed by the human brain. Are they stored and accessed holistically, or are they parsed as sequences of morphemes connected together through rules similar to those that connect words in a sentence, or both at the same time? What are the brain signatures for such processing? And are these neural mechanisms the same or different for complex words of different types, specifically for inflected and derived ones? The relationship between derivation and inflection, especially their neural underpinnings, has been a controversial issue in psycholinguistics and cognitive neuroscience of language. Some theoretical views suggest that all morphologically complex words are processed in a similar way, for instance, by undergoing morphological decomposition into their constituent morphemes (Rastle & Davis, 2008), while others postulate differential processing and representation for inflections and derivations (Bozic & Marslen-Wilson, 2010; Clahsen, Sonnenstuhl, & Blevins, 2003; Niemi, Laine, & Tuominen, 1994); furthermore, some accounts characterise all morphological effects as arising from the correlation between form and meaning (Gonnerman, Seidenberg, & Andersen, 2007; Seidenberg & Gonnerman, 2000).

Complex word processing has been particularly extensively studied in the visual modality. Studies using a visual masked priming paradigm, where the prime cannot be consciously perceived, have postulated automatic form-based morpho-orthographic decomposition obligatorily occurring during early stages of complex-word processing (Crepaldi, Rastle, Coltheart, & Nickels, 2010; Longtin & Meunier, 2005; Marslen-Wilson, Bozic, & Randall, 2008; Rastle & Davis, 2008), and this claim has gained support from event-related potential (ERP) and magnetoencephalography (MEG) studies (Lavric, Clapp, & Rastle, 2007; Lehtonen, Monahan, & Poeppel, 2011; Lewis, Solomyak, & Marantz, 2011; Solomyak & Marantz, 2010). However, the important consideration related to priming studies is that they speak more to the relationship between the probe and the prime than for the processing of the probe *per se*. Moreover, the information available for comprehension is present at different time points in visual and auditory modality: whereas written input is available for a reader at once, spoken words unfold over time thus providing cues to their morphological structure at distinct points in time. Using spoken stimuli may therefore allow for more precise dissociation of word processing mechanisms over time in the auditory modality.

As mentioned above, derivations change the lexical class of the word, which is not the case for inflections that only carry grammatical function. Moreover, derivations can change the meaning of a word, which may or may not be compositional with respect to the meaning of the constituents (cf. *depart–departure* and *depart–department*). Behavioural studies have shown that among others, transparency and affix productivity affect the strength of connection between stems and derivational suffixes and the degree of decomposition [e.g., (Bertram, Schreuder, & Baayen, 2000)]. Derivations may thus not be compositional in the same way as inflections are (Bozic & Marslen-Wilson, 2010).

Electrophysiological studies using experimental settings with overt attention on written and spoken linguistic stimuli have shown that well-formed inflected words pitted against matched monomorphemic real words elicit larger N400/N400m responses than monomorphemic words (Lehtonen et al., 2007; Leinonen et al., 2009; Leminen et al., 2011; Vartiainen et al., 2009), possibly reflecting lexical access and semantic integration of the morphemes. Moreover, when time-locked to the critical point (suffix onset and uniqueness point), inflected words elicit larger left-lateralised negativity as early as ~200 msec as compared to monomorphemic words (Leminen et al., 2011). On the other hand, the processing of derived forms has exhibited a somewhat consistent pattern of neural activity: some studies have reported left anterior negativity responses to morphologically complex words and pseudowords (Bölte, Jansma, Zilverstrand, & Zwitserlood, 2009; Palmovic & Maricic, 2008), interpreted to reflect structural problems due to morphological processing. In contrast, others have reported N400-like negativities for incorrectly derived words (Havas, Rodriguez-Fornells, & Clahsen, 2012; Janssen, Wiese, & Schlesewsky, 2006; Leinonen, Brattico, Järvenpää, & Krause, 2008; Leminen, Leminen, & Krause, 2010) suggested to reflect a failed access and/semantic integration of the morphemes.

In a recent electroencephalography (EEG)/MEG study (Leminen et al., 2011), the processing of inflected words activated more strongly left superior/middle temporal cortices, whereas this systematically localised left-hemispheric activity was not found for the derived words. On the other hand, derived words activated right superior temporal areas at ~100 msec after the suffix onset, this activation being of a significantly smaller scale for inflected words. A recent morphological priming ERP study on Spanish inflection and derivation also reported differences in amplitudes and source locations for the two word types (Alvarez, Urrutia, Dominguez, & Sanchez-Casas, 2011).

The findings from numerous functional magnetic resonance imaging (fMRI) and MEG studies underline the key role of the left fronto-temporal network in the processing of (regularly) inflected words (for a recent review, see Bozic & Marslen-Wilson, 2010). As for derived words, their processing is known to activate the left inferior frontal areas (Bozic, Marslen-Wilson, Stamatakis, Davis, & Tyler, 2007; Meinzer, Lahiri, Flaisch, Hannemann, & Eulitz, 2009; Vannest, Polk, & Lewis, 2005), basal ganglia (Vannest et al., 2005), as well as left, right, or bilateral occipital and temporal areas (Bölte, Schulz, & Dobel, 2009; Gold & Rastle, 2007; Lehtonen et al., 2011; Meinzer et al., 2009; Solomyak & Marantz, 2010; Zweig & Pylkkänen, 2008). Marangolo, Piras, Galati, and Burani (2006) reported that although production of derived forms shared some areas