(Online) ISSN 2709-7633 (Print) |ISSN 2709-7641
Publishers: Nobel Institute for New Generation
http://shnakhat.com/index.php/shnakhat/index

The Role of Morphological Processing In Brain: The Good Inflection and Bad Compounding

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Abstract

There is considerable behavioral evidence that morphologically complex words such as 'tax-able' and 'kiss-es' are processed and represented combinatorially. In other words, they are decomposed into their constituents 'tax' and '-able' during comprehension (reading or listening), and producing them might also involve one the espot combination of these constituents (especially for inflections). However, despite increasing amount of neurocognitive research, the neural mechanisms underlying these processes are still not fully understood. The purpose of this critical review is to offer a comprehensive overview on the state-of-the-art of the research on the neural mechanisms of morphological processing. In order to take into account all types of complex words, we include findings on inflected, derived, and compound words presented both visually and aurally. More specifically, we cover a wide range of electro- and magnetoencephalography (EEG and MEG, respectively) as well as structural/functional magnetic resonance imaging (s/fMRI) studies that focus on morphological processing. We present the findings with respect to the temporal course and localization of morphologically complex word processing. We summarize the observed findings, their interpretations with respect to current psycholinguistic models, and discuss methodological approaches as well as their possible limitations.

Keywords- Morphological Processing, Brain, Good inflection, Bad Compounding

Introduction

A significant portion of the psycholinguistic literature in the past several decades has been concerned with the processing of morphologically complex words. Despite an increasing number of studies on the neural underpinnings of morphological processing, its time-course and the underlying brain networks are still far from being clearly identified. In this paper, we present a much needed comprehensive review of the studies which have used some of the main neuroimaging methods, in order to grasp the state-of-the-art in the cognitive neuroscience of morphological processing. Thus, the main aim of this methodological review is to provide cognitive (neuro-) scientists interested in conducting neuroimaging research on morphological processing with a comprehensive summary of the most relevant neuroimaging research on this matter.

This review mainly focuses and pivots on the experimental methods, and especially on three neuroimaging techniques that are of great relevance for the field, summarizing evidence from studies using Electroencephalography (EEG), Magnetoencephalography (MEG) and structural and functional Magnetic Resonance Imaging (MRI). The review is organized in three main sections corresponding to the three main morphological operations: inflection, derivation, and compounding. In each of the sections, the evidence provided by neuroimaging studies using the three main techniques mentioned above is discussed. We selected only studies that were conducted with a) adult, b) healthy, c) native speakers of the test language d) without reading difficulties. In most cases, the participants of the reviewed studies are students at universities (whose reading skills are usually not assessed). We thus have not included studies on language acquisition or on special populations, even if they report a comparison to a control group (i.e. healthy, adult, native speakers with unimpaired reading skills), with the exception of a handful of studies that (a) report native and nonnative speakers together in the absence of between group differences, (b) tested simultaneous bilinguals (2 L1s) in both their languages and (c) link brain structure to morphological processing, which we consider relevant and timely.

To this end, the review of functional MRI studies includes 22 studies on inflections, 18 on derivations (note that studies that looked at both inflection and derivation are counted twice) and three on compounding, plus three structural MRI studies; the review of MEG studies includes 7 studies on inflections, 10 on derivations, and two on compounding, and the review of EEG studies provides a selection of 28 papers on inflections, 19 on derivations, and 13 on compounding. This means that the review for MRI and MEG studies is exhaustive at the time of writing of this paper. Because the number of EEG studies on morphological processing is close to hundred, the present review for EEG studies has to be selective, but care was taken that the most relevant and known studies have been included. In addition, we attempt to review and combine those studies that link a specific morphological function (e.g. decomposition/pars

Derivational morphology

Derivational morphology concerns the way new lexical representations are created by combining a base (namely, the root or stem) with one or more affixes (e.g., prefixes, suffixes, 18 cortex 116 (2019) 4 e4 4 infixes) to create polymorphemic words (for reviews, see Aronoff & Fudeman, 2010; Lieber, 2016; Milin, Smolka, & Feldman, 2017). But what do neuroscientific research and polymorphemic words have in common? Leaving aside the debate on whether neurolinguistics can really inform us about the nature of morphological processing, the most salient answer to this question at the surface level would be that they share the presence of several affixes in the adjectives of the noun phrases: neuro- þ science þ -ic and poly- þ morpheme þ -ic. We may not fully understand yet how polymorphemic words are represented, decomposed and processed in the brain, but without exception we would all agree that such words have lexical representations that include at least two morphemes (and hence the poly-).

And how do we know that on the basis of a unique lexical representation like "polymorphemic"? That is precisely the focus of the current section in which neuroscientific studies on derivational morphology will be reviewed and discussed in an attempt to comprehensively summarize how, when and where in the brain derived words are decomposed and their morphological constituents processed. In this line, a critical question in the field has been the specific lexico-semantic status held by different types of morphemic representations and the way they parse to create the emerging property of the combinatorial morphology. The greatest issue that has become the focus of attention and debate for several decades is whether or not individual morphemes that constitute a polymorphemic affixed word (e.g., the stem dark and the suffix ness in the suffixed word darkness) are accessed prior to reaching the meaning of the whole string (namely, the meaning of darkness), and if that were the case, the precise stage of the word recognition stream at which access to the stems and affixes may take place.

While at first sight it seems relatively straightforward to realize that an English suffix like -ness is not a free-standing morpheme that could act nearly as a lexical item, it is also commonly accepted that this bound morpheme typically attaches to participles and adjectives, consistently creating abstract nouns denoting quality, condition or state like in darkness (see Medeiros & Dunabeitia, 2016 ~). In fact, and in line with the seminal ideas on affix stripping proposed by Taft and Forster (1975), nowadays most researchers would agree that the processing of a word like darkness would be mediated by, or at least implies, a mandatory decomposition into the constituent morphemes by stripping the suffix ness from the stem dark. However, the affix stripping is a rule of thumb that does not apply equally to all circumstances. For example, consider the obvious differences between the saliency of a free-standing stem like "dark" stripped from "darkness", and of other bound stem morphemes with no lexical entries matching exactly the result of the dissection deriving from the morphological parsing (e.g., wae from waeness, which is a form of the word woeness), or even of pseudo-stems that do not pair with any close representation and which call into question the morphological status of the elements (e.g., wit from witness).

Thus, while there is little debate on that the morphological units of derived words are accessed during word processing, the discussion focuses on the specific moment in which each of the units is accessed and processed, and the way this speaks for individual differences in the concrete properties of the polymorphemic words and of the readers of listeners that process them. Different units may be readily available for processing and segmentation at different stages of the recognition process, and different properties of the bound and free-standing morphemes (e.g., Forster & Azuma, 2000; Moscoso del Prado Martı´n, Kostic, & Baayen, 2004; Pastizzo & Feldman, 2004), as well as individual differences in the persons processing these units (e.g., Andrews & Lo, 2013; Dunabeitia, Perea, ~ & Carreiras, 2014; Medeiros & Dunabeitia, 2016 ~) have been shown to modulate morphological decomposition mechanisms (see Amenta & Crepaldi, 2012, for review).

As mentioned, the last decade has witnessed an increasing body of evidence showing somewhat conflicting results with markedly different theoretical implications on the extent to

(Online) ISSN 2709-7633 (Print) |ISSN 2709-7641
Publishers: Nobel Institute for New Generation
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what morphological decomposition of derived words takes place at early or late stages of word recognition, mainly linked to either orthographic or semantic processes (see Beyersmann et al., 2016, for a comprehensive review). Given the bulk of evidence showing that non-existing seemingly polymorphemic representations lacking a lexical status (e.g., pseudowords like quickify) are, in fact, decomposed into the constituent pseudo-morphemic units (e.g., Beyersmann, Dunabeitia, Carreiras, Coltheart, ~ & Castles, 2013; Longtin & Meunier, 2005; Meunier & Longtin, 2

Violations

A significant number of studies applied violations to study the morphosyntactic processing of derivations. For example, Bolte, € Jansma, Zilverstand, and Zwitserlood (2009) applied violations to German adjective derivations, presented in sentence context. They compared the processing of correct adjectives (e.g., freundlich, 'friendly') with two types of violations: possible but nonexisting adjectives (e.g., *freundhaft, '*friendful'), and anomalous adjectives (e.g., *freundbar, '*friendive'). Both types of violations induced LAN effects relative to correct derivations, with no difference between them. These findings were interpreted as evidence for morphological decomposition and for a separate handling of structural and semantic information. Also, Leinonen, Brattico, Jarvenp € a€a, and Krause (2008) € presented violated derivations in sentence context. Relative to the correct derivations (noun stem þ suffix), the violated derivations (verb stem þ suffix) elicited N400 effects. The authors interpreted these findings as reflecting the parsing of the morpheme combination or as the unsuccessful (or laborious) semantic integration of the morphemic constituents (see also Janssen, Wiese, & Schlesewsky, 2006 for similar N400 findings and violation types in single word context). Turning to single word studies, in Leminen, Leminen, and Krause (2010) participants made auditory lexical decisions to existing derivations and legal novel derivations in Finnish. Both types elicited N400-like negativities that did not differ from each other and were thus interpreted as evidence for the successful parsing of novel derivations.

Morphological priming masked

To establish morphological effects, form priming was typically compared with the effects of morphological conditions, which were identical words (e.g., tableetable) or semantically

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transparent morphological derivations (e.g., hunterehunt, government-govern). Under masked visual priming, morphologically related (semantically transparent or identical) word pairs like hunterehunt or tableetable induced either an N250 attenuation alone (Morris et al., 2008) or both N250 and N400 attenuations (Beyersmann, Iakimova, Ziegler, & Cole, 2014; Holcomb & Grainger, 2006; Morris, Frank, Grainger, & Holcomb, 2007; Morris et al., 2008, 2011, 2013; Lavric, Clapp, & Rastle, 2007).

The morphology of compounding

Most languages use compounding as the main morphological operation to create new lexical items (see Pollatsek, Bertram, & Hyon€ a, 2011 €). Given the huge number of novel compounds that can be created by concatenating different word types, compound words have been considered as the morphological foundation of lexical productivity (cf. Libben, 2014). In contrast to other rule-based operations that follow relatively strict parsing criteria (like the grammatical operations yielding inflectional morphology, or the precise position within the strings of certain types of derivational affixes), compounding is governed by more malleable principles. Take, for instance, the word man. By simply concatenating the derivational affix -ly one can get the derived word manly. But the properties and rules of derivational operations and of the specific morphemes state that -ly cannot be used as a prefix, given that it is a suffix and its expected position is after, and not before, the base form. However, a markedly different scenario is offered by compound word creation, insofar the lexeme man can be freely used in different positions within a compound, being the first constituent lexeme in manpower, or the second constituent in milkman.

This relative freedom in positioning a given constituent morpheme within a compound means that there are different possibilities for compound word construction, and that two or more elements can be differently combined to create a compound. Closed compounds are the prototypical form of lexicalized compounds, and they present a series of constituent morphemes

SHNAKHAT
(Online) ISSN 2709-7633 (Print) |ISSN 2709-7641
Publishers: Nobel Institute for New Generation
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that are concatenated creating a single non-spaced and non-hyphenated lexical representation (e.g., postman). But in some other circumstances, compound words are created by separating the constituent morphemes by a hyphen (e.g., man-made), or by separating the morphemes by a space (e.g., straw man). Thus, compounding offers a large variety of possible operations to create morphologically complex items, and for this reason compound word processing has been in the focus of psycholinguists exploring word creation and decomposition (see Juhasz, 2018, for review). A great body of studies has focused on the specific properties of the constituent morphemes in closed, or lexicalized, compounds, which modulate lexical access and morphological decomposition (see Juhasz, Lai, & Woodcock, 2015; Kuperman, 2013).

In order to study this, most experiments have either manipulated the frequencies of the constituents (e.g., Andrews, Miller, & Rayner, 2004; Bertram & Hyon€ a, 2003; € Pollatsek, Hyon€ a, € & Bertram, 2000), the semantic transparency of the whole compound and of its parts (i.e., opaque vs. transparent compounds; e.g., Juhasz, 2007; Marelli & Luzzatti, 2012; see Libben, 1998, for discussion on this matter), or the 28 cortex 116 (2019) 4 e4 4 Table 6 e Summary of fMRI studies on derivation. All studies used single word tasks. Only findings related to morphological decom Violations Violation paradigms have been used to study the morphosyntactic processing of compounds. For example, Koester and colleagues (Koester, Gunter, & Wagner, 2007; Koester, Gunter, Wagner, & Friederici, 2004) applied gender violations to the first or second constituent of German compounds and manipulated the gender agreement between a determiner and the first constituent or the head of existing 2-word compounds (e.g., *der Reisfeld, '*themasc ricemasc fieldneuter') or novel three-word compounds (e.g., *das Sofakissenbezug, '*theneuter sofaneuter pillowneuter covermasc'). Participants judged the gender agreement of the compound. Although the gender of the first constituent is irrelevant in German, gender-incongruent first constituents induced a LAN effect.

This implies that the gender feature of the first constituent was accessed. Furthermore, gender-incongruent heads induced a LAN and a late positivity, independent of the compound's transparency. This was taken to suggest that both transparent and opaque compounds are decomposed, and that both first constituents and heads are accessed morphosyntactically. In a comparison to low-frequency 2- word compounds, transparent compounds showed a slow negative shift (600e1200 msec), which was interpreted to reflect the semantic processing and integration of the constituents. The authors concluded that all compounds, transparent and opaque, are morphologically complex, but only (low-frequent) transparent compounds are semantically complex (for similar behavioral results see Dohmes, Zwitserlood, & Bolte, 2004).

Conclusion

What these results also mean is that the regular inflected 'whole form' cannot be stored as the perceptual target for lexical access. If the access route for *joined* were via a representation of *joined* as a whole form, then there would be no reason for access to fail here when it was succeeding for other whole-form representations like *found* or stem representations like *hope*. This, in turn, means that inflected regular forms must be subjected to some form of morpho-phonological parsing, which breaks down the surface full form into its stem+affix components. Without such decomposition, the full inflected form is an ill-formed input to the lexical access process, not matching fully with any stored representation. Further work with the same type of LH non-fluent patients sheds additional light on these decompositional processes, showing them to be applied early and obligatorily to the speech input and highlighting the priority that the system seems to assign to the detection of inflectional morphemes and their separation from their stems. The evidence for this comes from an auditory same–different task, where patients were presented with two successive words (or non-words), spoken in a male and a female voice, and asked to judge whether the second word/non-word in each pair was the same as the first (Tyler *et al.* 2002*b*).

Successful performance in this apparently simple task requires the participant to construct a stable internal representation of the first stimulus heard, so that this can be held in memory for comparison with the second member of the pair. The pattern of successes and failures for the non-fluent patients indicates the importance of morpho-phonological parsing in constructing these representations. The patients had problems not only with regularly inflected real words—in pairs like *played/play*—but also with any other stimulus pairs—even non-words like *snade/snay*—that ended in the characteristic phonetic pattern associated with regular inflectional morphology in English and which were therefore potentially decomposable. This pattern—the presence of a coronal consonant (d, t, s, z) that agrees in voice with the preceding phoneme—holds without exception for the two dominant regular inflectional paradigms in

(Online) ISSN 2709-7633 (Print) |ISSN 2709-7641
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English, the past tense {-d} and the {-s} inflection. We have labelled this the English *inflectional rhyme pattern* (IRP).

In the experiment, we compared performance on real regular pairs (*played/play*)[6] with two other sets that shared this IRP. These were pseudo-regular pairs like *trade/tray*, where *trade* is homophonous with the potential but non-existent past tense of the noun *tray*, and non-word regular pairs like *snade/snay*, where neither is a word in English, but where *snade* could be the past tense of the (non-existent) stem *snay*. These three sets contrast with two sets of word/non-word pairs which are matched to the inflectional sets in terms of consonant–vowel (CV) structure, with the final phoneme being dropped in the second member of the pair, but where this final phoneme is not a possible inflectional affix in English—as in pairs like *claim/clay* or *blane/blay*. Although *claim* contains the imbedded word *clay*, much as *trade* contains *tray*, it cannot be interpreted as a morphologically complex form and does not invite morpho-phonological parsing and decomposition. For the non-word *blane*, there is similarly no indication that it is the inflected form of a potential real stem.

The results show a striking divergence between the inflectional sets and the additional phoneme sets. Although patients perform worst on the real regulars, they also perform remarkably poorly on the pseudo-regular and non-word regular sets, while being close to normal on the two additional phoneme sets. These effects show up significantly in their response times, but can be seen most dramatically in the pattern of errors (defined as a failure to detect a difference. In the context of near-zero error rates for the age-matched controls (means of 1.7% for non-words and 0.6% for real words), the patients fail to detect a *played/play* difference over 30% of the time, with error rates well above 20% for the pseudo-regular and the non-word conditions. In contrast, they make less than 5% errors on the matched additional phoneme conditions.[7]

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