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Electrophysiological evidence for a neural substrate of morphological rule application in correct wordforms

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ABSTRACT

A critical issue for understanding language processing in the brain is whether linguistic rule application is subserved by a distinct neural substrate. One of the evidence supporting this hypothesis stems from studies employing electroencephalographic measurements during the processing of rule misapplication. This evidence is inconclusive because it might reflect processes caused by the violation such as error handling rather than application of rules per se. Here we provide first evidence that correct regular formations, i.e., German past participles, are associated with left anterior negative-going activity (LAN) providing encephalographic evidence for rule application in the brain during the processing of correct words. Moreover, a LAN response is present regardless of the participles' frequency, suggesting that independently from the mode of lexical access (i.e., decomposition or full-form activation), the cerebral structures associated with rule-based mechanisms are activated.

1. Introduction

One of the unique human capacities is the ability to produce and understand an infinite number of linguistic forms such as sentences or complex words (Corballis, 1992). Following Chomsky (1965) and Chomsky and Halle (1968), many scholars have captured this capacity by distinguishing between default rules that underlie our production and understanding of complex forms and a mental lexicon (the storage system) holding the units that the rules apply to. This has led to dual-mechanism accounts of inflectional morphology, which assume two innate but distinct neural systems: a procedural system that applies rules and a lexical storage system that stores exceptions to the rules (e.g., Clahsen, 1999; Pinker, 1999a; Pinker and Ullman, 2002; Prasada and Pinker, 1993; Ullman, 2001). For instance, the regular form *walked* is understood as a result of a mental operation that combines the stem *walk* with the regular suffix *-ed*, while the irregular form *went* is assumed to be stored in the mental lexicon. For the comprehension of inflected words, it is assumed that regular forms are decomposed into stems and affixes, while irregular forms are accessed as full-forms without decomposition.

However, this distinction between rules and lexical storage is controversial and has led to an intense debate in psychology and linguistics. Supporters of single-mechanism accounts propose that a single system handles both regular and irregular words and that rules are mere epiphenomena of similarities of forms and are not subserved by a distinct neural substrate (e.g., Joanisse and Seidenberg, 2005; McClelland and Patterson, 2002; Rumelhart and McClelland,

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1986; Smolka et al., 2007). Single-systems are often modeled as connectionist networks, which represent single associative memory systems that represent both regular and irregular word forms and map, for instance, verb stems onto past tense forms (e.g., Rumelhart and McClelland, 1986).

Evidence for rule application as a separate neural process has been sought, for example, by measuring event-related potentials (ERPs) employing electroencephalography (EEG). Using a violation paradigm, i.e., presenting correctly and incorrectly formed morphological words, it has been reported that incorrect forms such as *goed* (as opposed to correct *went*), in which the *-ed* rule is incorrectly applied (rule violation), are associated with an increased left anterior negative-going activity (LAN), typically occurring between 300 and 500 ms, when compared with correct forms. However, the LAN does not occur for incorrect forms such as *bept* (as opposed to correct *beeped*), which is simply a nonword that does not violate the *-ed* rule (Gross et al., 1998; Linares et al., 2006; Morris and Holcomb, 2005; Penke et al., 1997; Rodriguez-Fornells et al., 2001; Weyerts et al., 1997). This dissociation has been found in several languages and the LAN has typically been interpreted as a cerebral response to the misapplication or violation of rules. While this dissociation suggests different processing mechanisms for regular and irregular formations, the LAN is a very indirect evidence for a distinct neural substrate for rule application because studies to date have focused on the processing of violations of rules rather than on rule application per se. The LAN might therefore merely reflect exceptional processes that are caused by the violation such as error handling and not by actual rule application. This is in line, for instance, with the suggestion that LANs might not be related to regular processes but caused by the mismatch of the presented incorrect form of a word with its stored correct form (Krott et al., 2006).

The strict distinction between decomposition for regular verbs and full-form access for irregular forms in dual-mechanism accounts has been qualified in response to studies that found an effect of the frequency of the inflected forms, i.e., of full-form frequency, on the processing of regularly inflected forms, suggesting that high-frequency regular inflections develop full-form access representations just like irregular words (e.g., Alegre and Gordon, 1999; Baayen et al., 1997; Bertram et al., 2000; New et al., 2004; Schreuder and Baayen, 1995; Sereno and Jongman, 1997). Furthermore, the recognition of low-frequency regular inflections is typically slower and leads to more errors than that of low-frequency irregular inflections, suggesting that low-frequency regular forms are recognized via the decomposition route as decomposition is believed to be slower and more error-prone than full-form activation. Full-form storage for high-frequency words is economical as it guarantees fast access of frequently occurring forms.

Previous LAN studies have not addressed the dissociation between high and low frequency regular forms observed behaviorally. If high frequency regular forms are accessed via full-form activation, rule processes might be activated only for low frequency regular forms and not for high-frequency regular forms. This would be in line with the assumption that stored forms block the application of a rule (e.g., Clahsen et al., 2004; Marcus et al., 1995; Pinker, 1999b). Alternatively, high-frequency regular forms might simultaneously activate full-form representations and are processed via decomposition, as proposed in more general dual-route models of morphological processing (Chialant and Caramazza, 1995; Niemi et al., 1994; Schreuder and Baayen, 1995). Behavioral studies cannot distinguish between these two possibilities because they cannot detect processes that do not have an impact on the behavioral response. However, evidence of such 'silent' process can be detected if they leave traces on the ERPs.

The present study seeks for the first time electroencephalographic evidence for rule processing by focusing on correct forms and avoiding the disadvantage of investigating the effects of rule violation. In addition, it investigates whether electrophysiological responses can confirm the behavioral dissociation between high and low frequency regular forms, by presenting both high and low frequency forms for both regular and irregular forms. Last but not least, it compared forms with correct suffixes with incorrect suffixes, in order to investigate the robustness of the LAN found for overregularisation errors (Gross et al., 1998; Linares et al., 2006; Morris and Holcomb, 2005; Penke et al., 1997; Rodriguez-Fornells et al., 2001; Weyerts et al., 1997).

We presented correct and incorrect regular and irregular German participles, which are formed by adding a prefix *ge-* to a verb stem plus either the suffix *-(e)t* (*ge-glaub-t* 'believed') or the suffix *-(e)n* (*ge-fahr-en* 'driven'). Thus, we presented the correct forms *geglaubt* and *gefahren* as well as the incorrect forms *geglauben* and *gefahrt*. The prefix *ge-* is occasionally dropped when the verb contains a prefix (e.g., *unterschrieben* 'signed'), and some types of irregular verbs have different stem vowels for the infinitive (*schwimmen* 'to swim') and the past participle (*geschwommen* 'swum'). In the present study, however, only past participles that contain the prefix *ge-* and that do not exhibit a vowel change were used. Of the two suffixes, *-(e)t* is understood as being the regular one and *-(e)n* the irregular one. This distinction is based on a number of differences between the two suffixes. Only the suffix *-(e)n* occurs with unpredictable stem vowel allomorphy (*rennen* 'to run'—*gerannt* 'run' (past participle)) and therefore behaves very similar to English irregular past tense and past participles (Clahsen, 1997). During the acquisition of the participles children often overuse *-(e)t* with irregular verbs (incorrect *gekommt* instead of correct *gekommen* 'come'), but rarely overuse *-(e)n* with regular verbs (incorrect *geschneien* instead of correct *geschneit* 'snowed') (Clahsen and Rothweiler, 1993). These results are closely related to the suffixes' productivity in adult language. While *-(e)t* is used to produce participles with novel verbs (e.g., with the nonsense verb *faben*: *ge-fab-t*), *-(e)n* is very rarely used for this purpose and only if the new stem resembles an existing stem that also takes *-(e)n* (e.g., Clahsen, 1999; Marcus et al., 1995). Also, the *-(e)n* of low frequency participles is often replaced by *-(e)t* (e.g., Marcus et al., 1995).

We focused on German past participles for two reasons. First, unlike English irregular verbs which tend to occur in phonological clusters such as *drink, sink, sing* etc. that help to predict the form of similar past participles (*drunk, sunk, sung* for the above mentioned example), German verb stems do not provide any reliable indication of whether they are irregular or regular (Beedham, 1994). This means that only the suffix *-(e)t* can be described by means of a rule. Second