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Brain responses to filled gaps

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Abstract

An unresolved issue in the study of sentence comprehension is whether the process of gap-filling is mediated by the construction of empty categories (traces), or whether the parser relates fillers directly to the associated verb's argument structure. We conducted an event-related potentials (ERP) study that used the violation paradigm to examine the time course and spatial distribution of brain responses to ungrammatically filled gaps. The results indicate that the earliest brain response to the violation is an early left anterior negativity (eLAN). This ERP indexes an early phase of pure syntactic structure building, temporally preceding ERPs that reflect semantic integration and argument structure satisfaction. The finding is interpreted as evidence that gap-filling is mediated by structurally predicted empty categories, rather than directly by argument structure operations.

Keywords: Event-related potentials; LAN; ELAN; Sentence comprehension; Gap-filling; Filled-gap effect; Long-distance dependencies; Empty categories

1. Introduction

1.1. Background

A central property of natural language syntax is the *displacement property* (Hauser, Chomsky, & Fitch, 2002), whereby a word or phrase occurs in a syntactic position that is different from the position which determines its basic semantic role. This is illustrated by the relative clause construction (1b), where *the zebra* has been displaced from the object position of *kissed* in (1a):

(1) a. [The hippo kissed the zebra on the nose] and then ran far away.
b. [The zebra that the hippo kissed on the nose] ran far away.

Generative linguistic theory (Chomsky, 1981, 1995) models the displacement property by a transformation that moves the object to a higher syntactic position, leaving a silent copy in the original object position (a "trace" or a "gap"). This ensures that the displaced phrase is interpreted as the object of the verb, just as a non-displaced phrase would be. Alternatively, other theories model displacement without the use of syntactically represented traces. Generalized Phrase Structure Grammar (Pollard & Sag, 1993; Sag & Fodor, 1995) relies on feature transmission in trace-less syntactic representations, and Lexical-Functional Grammar (Bresnan, 2001) encodes the relationship at a functional, non-syntactic level of representation. In this article, we present experimental results that have a bearing on whether displacement should be modeled by a syntactically present trace or not. The premise is that the representations postulated by linguistic theories can be viewed as being constructed in real time by psycholinguistic processing mechanisms, and that consequently, empirical findings about processing can be used to decide between theories of representation. We next review how the two theoretical approaches to displacement find their correlates in two alternative processing models, and how electrophysiological measures can be used to differentiate between the theories.

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In psycholinguistics, the problem of reconstructing the filler's semantic role is known as "gap-filling", and can be characterized as follows: After a phrase has been identified as a filler, it must be kept in working memory until a verb is found that it can be related to. In (1b), no noun phrase follows *kissed*, which suggests that an object is missing in this position. At this point in time, the filler can be identified as the object of the verb *kissed* and integrated with the verb's argument structure. Evidence for this dynamic process of storage and reintegration has come from studies which show that the semantic information associated with the filler is "reactivated" at the gap position (Bever & McElree, 1986; Nicol, Fodor, & Swinney, 1994; Shapiro, Swinney, & Borsky, 1998; Swinney, Ford, & Bresnan, 1989; Swinney & Osterhout, 1990; Swinney & Zurif, 1995). Reactivation has been taken as evidence that the parser constructs a mentally represented trace (Clifton & Frazier, 1989), but the effect is also consistent with a model where the filler associates directly with the verb's argument structure (Pickering, 1993; Pickering & Barry, 1991; Sag & Fodor, 1995; Traxler & Pickering, 1996). According to these authors, gap-filling involves identifying a verb and associating the filler directly with an unsaturated position in the argument structure of the verb, obviating the need for a trace. In these accounts, the reactivation effect comes from the processing of the verb itself.

Some authors have argued against direct association by demonstrating that antecedents are reactivated in trace positions that are non-adjacent to the verb. For example, reactivation has been reported for pre-verbal object gaps in verb-final languages (Clahsen & Featherston, 1999; Nakano, Felser, & Clahsen, 2002), as well as for post-verbal but non-adjacent object positions in English (Roberts, Marinis, Felser, & Clahsen, in press). However, Phillips and Wagers (in press) counter that this argument is inconsistent with look-ahead effects in parsing (Crocker, 1996; Gibson & Hickok, 1993), where a verb position is constructed in advance of the verb itself. If so, the argument goes, direct association could be made to account for these results as well.

Another source of evidence that could distinguish between direct association and the trace model comes from the *active filler* strategy (Frazier & Clifton, 1995; Frazier & Fodor, 1978). This strategy entails that the parser continuously makes guesses about which structure to build next as each new word is perceived. In the context of gap-filling, the parser's eagerness to complete long-distance dependencies then sometimes leads it to posit gaps prematurely, which in turn leads to "surprise" effects and reanalysis when the error is discovered (Clifton & Frazier, 1986, 1989; Crain & Fodor, 1985; Frazier & Flores d'Arcais, 1989; Stowe, 1986; Stowe, Tanenhaus, & Carlson, 1991). For example, Clifton and Frazier (1989) observed longer reading times after *to his fiancée* in sentences such as (2b) compared with (2a) (***t*** denotes the gap position):

(2) a. What$_i$ did the cautious old man whisper $\mathbf{t}_i$ to his fiancée during the movie last night?
b. What$_i$ did the cautious old man whisper ($\mathbf{t}_i$) to his fiancée about $\mathbf{t}_i$ during the movie last night?

Their explanation is that the parser initially posits a trace after *whisper* in both cases. This will eventually be correct in (2a). However, when encountering *about* in (2b), the analysis must be revised, because the parser now realizes that the verb is the intransitive version of *whisper*, followed not by a trace but by the PP *to his fiancée*. The increased reading time at *about* is interpreted as a reflection of this revision. However, Phillips and Wagers (in press) argue that this effect is also consistent with the direct association hypothesis. They suggested that the effect could be caused by the parser first associating the filler with the argument structure of a transitive version of *whisper*. Once *about* is encountered, the verb is reanalyzed as intransitive, and a new search is initiated for an argument taker with which to associate the filler. Phillips and Wagers (in press) conclude that neither antecedent reactivation nor the filled-gap effect provide clear evidence for syntactic traces during processing, and that what is missing from previous research is a clear timing prediction that distinguishes between direct association and the trace model.

1.2. Electrophysiology and the time course of sentence processing

We suggest that this kind of timing prediction is provided by the neurophysiological time course model of syntactic parsing developed by Friederici and her colleagues (Friederici, 1995, 2002; Friederici, Hahne, & Mecklinger, 1996, 1998). Friederici's model claims that sentence comprehension proceeds through several distinct phases in time, where each phase is related to different aspects of processing. Violations during each phase can be measured and associated with distinct "signature" event-related potentials (ERPs). In particular, early syntactic structure building processes take place during the 100–200 ms time region after phonetic analysis. Violations of word category expectations and phrase structure rules during this phase are associated with an early left anterior negativity (eLAN) with a peak latency around 150 ms (Friederici et al., 1996). During the next phase, the 300–500 ms time range, processes of argument structure satisfaction and semantic role assignment take place, as well as morphosyntactic agreement processes. Violations during this phase result in a centro-parietal negativity, the N400 (Kutas & Hillyard, 1980) for argument structure violations, and a left anterior negativity (LAN) for morphosyntactic agreement violations (Friederici, Pfeifer, & Hahne, 1993, 1996). Finally, a third late phase is for processes of reanalysis and repair. The ERP associated with this stage is the P600, a large amplitude posterior positivity in the 500–700 ms range. The P600 appears to index phrase structure assignment errors and