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Prominence vs. aboutness in sequencing: A functional distinction within the left inferior frontal gyrus

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ABSTRACT

Prior research on the neural bases of syntactic comprehension suggests that activation in the left inferior frontal gyrus (lIFG) correlates with the processing of word order variations. However, there are inconsistencies with respect to the specific subregion within the IFG that is implicated by these findings: the pars opercularis or the pars triangularis. Here, we examined the hypothesis that the dissociation between pars opercularis and pars triangularis activation may reflect functional differences between clause-medial and clause-initial word order permutations, respectively. To this end, we directly compared clause-medial and clause-initial object-before-subject orders in German in a within-participants, event-related fMRI design. Our results showed increased activation for object-initial sentences in a bilateral network of frontal, temporal and subcortical regions. Within the lIFG, posterior and inferior subregions showed only a main effect of word order, whereas more anterior and superior subregions showed effects of word order and sentence type, with higher activation for sentences with an argument in the clause-initial position. These findings are interpreted as evidence for a functional gradation of sequence processing within the left IFG: posterior subportions correlate with argument prominence-based (local) aspects of sequencing, while anterior subportions correlate with aboutness-based aspects of sequencing, which are crucial in linking the current sentence to the wider discourse. This proposal appears compatible with more general hypotheses about information processing gradients in prefrontal cortex (Koechlin & Summerfield, 2007).

1. Introduction

During real time communication, language unfolds over time, and, as a result, language understanding must proceed in a sequential manner. Hence, the order in which the words that make up a sentence occur crucially constrains the possible ways in which that sentence can be understood. In view of these considerations, it is not surprising that word order variations have played an exceptionally important role in investigations of the functional neuroanatomy of language processing. Over several languages (e.g. English, German, Hebrew and Japanese) and different sentence types (relative clauses, questions, declarative sentences), researchers have consistently observed increased activation in the left inferior frontal gyrus (lIFG) for sentences with object-before-subject orders in comparison to their subject-initial counterparts (e.g. Just, Carpenter, Keller, Eddy, & Thulborn, 1996; Stromswold, Caplan, Alpert, & Rauch, 1996; Bahlmann, Rodriguez-Fornells, Rotte, & Münte, 2007; Ben-Shachar, Hendler, Kahn, Ben-Bashat, & Grodzinsky, 2003; Ben-Shachar, Palti, & Grodzinsky, 2004; Caplan, Alpert, & Waters, 1998; Caplan, Alpert, Waters, & Olivieri, 2000; Constable et al., 2004; Cooke et al., 2001; Fiebach, Schlesewsky, Lohmann, von Cramon, & Friederici, 2005; Fiebach, Vos, & Friederici, 2004; Friederici, Fiebach, Schlesewsky, Bornkessel, & von Cramon, 2006; Keller, Carpenter, & Just, 2001; Kinno, Kawamura, Shioda, & Sakai, 2008; Röder, Stock, Neville, Bien, & Rösler, 2002).[1] From these findings, it has been concluded that object-initial sentences are more complex to process, leading to measurably increased processing demands in healthy individuals and to comprehension deficits in patient populations (e.g. Caramazza & Zurif, 1976; Drai & Grodzinsky, 2006).

1.1. Prominence information and sequencing

Recent research suggests that, rather than being primary to the activation of the lIFG, the relative ordering of subject vs. object is only a subcase of more general requirements concerning the

[1] Object-initial orders have also been shown to engender different event-related potential (ERP) signatures to their subject-initial counterparts (e.g. Bornkessel, Fiebach, & Friederici, 2004; Felser, Clahsen, & Münte, 2003; Fiebach, Schlesewsky, & Friederici, 2002; Hagiwara, Soshi, Ishihara, & Imanaka, 2007; Matzke, Mai, Nager, Rüsseler, & Münte, 2002; Phillips, Kazanina, & Abada, 2005; Rösler, Pechmann, Streb, Röder, & Hennighausen, 1998; Ueno & Garnsey, 2008; Ueno & Kluender, 2003).

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sequencing of information within a sentence.[2] Thus, the degree of activation engendered by a particular word order depends on a variety of different information types that go beyond the mere subject–object dichotomy. For example, Chen, West, Waters, and Caplan (2006) found that the lIFG activation increase for object vs. subject-relative clauses in English depends on the animacy of the sentence participants (cf. example 1). Whereas object-relative clauses with an animate head noun and an inanimate relative clause subject (1a) engendered the typical pattern of increased lIFG activation (pars opercularis and pars triangularis) in comparison to minimally differing subject-relative clauses, object-relative clauses with an inanimate head noun and an animate relative clause subject (1b) did not.

(1) Example stimuli from Chen et al. (2006)
(a) The golfer that the lightning struck survived the incident.
(b) The wood that the man chopped heated the cabin.

Chen and colleagues' results suggest that the increased inferior frontal activation observed for object-relative clauses in previous studies cannot be reduced to the (syntactic or general cognitive) ramifications of an object-before-subject order. Rather, other factors must also be taken into account. This perspective is supported by a range of studies on German, which revealed that the pars opercularis of the lIFG (POp) is sensitive to various linearization parameters such as "animate-before-inanimate" (Grewe et al., 2006), "pronoun before non-pronoun" (Grewe et al., 2005), "definite/specific before indefinite/non-specific" (Bornkessel-Schlesewsky et al., 2009), and "higher thematic role before lower thematic role" (Bornkessel et al., 2005). Whereas some of these findings showed that object-initial orders do not engender increased activation in the pars opercularis when other linearization preferences are fulfilled (Bornkessel et al., 2005; Grewe et al., 2005), others even demonstrated increased activation for subject-initial in comparison to object-initial orders (Grewe et al., 2006) or between subject-initial orders (Bornkessel-Schlesewsky et al., 2009). Notably, the information types which have been shown to influence word order-related activation in the left pars opercularis are not arbitrary. Rather, these so-called "prominence scales" are well-known from cross-linguistic investigations because they influence morphosyntactic phenomena (e.g. case marking) in a range of typologically different languages (cf. Comrie, 1989; Croft, 2003).

In summary, a number of fMRI findings are indicative of a correlation between the left POp and the sequencing of linguistic information. Crucially, sequencing-related activation is modulated by a range of different information types (cf. Bornkessel-Schlesewsky & Schlesewsky, 2009).

1.2. Linguistic sequencing: pars opercularis or pars triangularis of the lIFG?

The vast majority of the studies discussed in the previous section showed increased word order-related activation in the left pars opercularis (POp). However, the assumption of a specific correlation between this subregion of the lIFG and sequencing/linearization processes is called into question by a number of findings showing word order-related activation maxima in the pars triangularis of the lIFG (PTr). These observations stem from German (Bahlmann et al., 2007), Hebrew (Ben-Shachar et al., 2004), and Japanese (Kinno et al., 2008).[3]

Interestingly, the sentence structures used in these studies suggest that there may be a principled reason for the distinction between POp and PTr activation in relation to word order variations. Whereas the many findings of POp activation in German all stem from studies which used clause-medial argument order permutations (Bornkessel et al., 2005; Bornkessel-Schlesewsky et al., 2009; Friederici et al., 2006; Grewe et al., 2005, 2007; Röder et al., 2002), the word order permutations in the studies reporting activation maxima in the PTr targeted the clause-initial position (Bahlmann et al., 2007; Ben-Shachar et al., 2004; Kinno et al., 2008). The distinction between these two types of word order permutations is illustrated on the basis of German in examples (2) and (3).

(2) Example of a clause-initial object-initial order in German, "topicalization" (from Bahlmann et al., 2007)
Den begabten Sänger entdeckte während der Weihnachtsfeier
[the gifted singer]$_{ACC}$ discovered during the christmas.party
der talentierte Gitarrist.
[the talented guitar.player]$_{NOM}$
'The talented guitar player discovered the gifted singer during the Christmas party.'

(3) Examples of clause-medial object-initial orders in German, "scrambling"
(a) Example sentence from Grewe et al. (2007)
Wahrscheinlich hat den Garten der Mann gepflegt.
likely has [the garden]$_{ACC}$ [the man]$_{NOM}$ taken.care.of
'The man likely took care of the garden.'
(b) Example sentence from Bornkessel et al. (2005)
... dass dem Jungen die Lehrer helfen.
... that [the boy]$_{DAT}$ [the teachers]$_{NOM}$ help
'... that the teachers help the boy.'

Based on this distinction, we propose that the difference between word order-related activation increases in the left PTr vs. POp may correlate with the distinction between the clause-initial and clause-medial positions of the clause. In the following section, we will discuss possible functional motivations for this differentiation.

[2] We have previously argued that this observation supports a "supra-syntactic" account of lIFG (and specifically pars opercularis) function in the processing of word order variations (Bornkessel, Zysset, Friederici, von Cramon, & Schlesewsky, 2005; Bornkessel-Schlesewsky, Schlesewsky, & von Cramon, 2009; Grewe et al., 2005; Grewe et al., 2006). However, which information types are viewed as syntactic depends on the particular theory of grammar which one adopts. Thus, the question of whether information types such as animacy and definiteness/specificity are to be viewed as syntactic or non-syntactic is perhaps not of primary importance to understanding the function of Broca's region in linguistic sequencing (word order). In this regard, we agree with Embick and Poeppel (2003), who argued that that the question of whether Broca's region mediates syntactic computation is too coarse at both a cognitive and a neuroanatomical level, since "'syntax' is not a single, monolithic task, nor is 'Broca's area' a single, monolithic area of the brain". In this paper, we therefore abstract away from questions regarding syntactic vs. non-syntactic processes or representations and rather focus on the specific requirements of different aspects of sequencing.

[3] Two recent neuroimaging studies on English have also revealed word order-related activations in the POp (Santi & Grodzinsky, 2007a) and PTr (Santi & Grodzinsky, 2007b) of the left IFG, respectively. At a first glance, this variability across experiments appears difficult to explain because both studies were conducted in a highly comparable manner and, according to the authors, with a comparable manipulation. Nevertheless, these findings also indicate that it is important to shed further light on the precise functional role of the different subregions within the left IFG during the processing of word order.