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Grammatical number agreement processing using the visual half-field paradigm: An event-related brain potential study

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ABSTRACT

Despite indications in the split-brain and lesion literatures that the right hemisphere is capable of some syntactic analysis, few studies have investigated right hemisphere contributions to syntactic processing in people with intact brains. Here we used the visual half-field paradigm in healthy adults to examine each hemisphere's processing of correct and incorrect grammatical number agreement marked either lexically, e.g., antecedent/reflexive pronoun ("The grateful niece asked herself/*themselves…") or morphologically, e.g., subject/verb ("Industrial scientists develop/*develops…"). For reflexives, response times and accuracy of grammaticality decisions suggested similar processing regardless of visual field of presentation. In the subject/verb condition, we observed similar response times and accuracies for central and right visual field (RVF) presentations. For left visual field (LVF) presentation, response times were longer and accuracy rates were reduced relative to RVF presentation. An event-related brain potential (ERP) study using the same materials revealed similar ERP responses to the reflexive pronouns in the two visual fields, but very different ERP effects to the subject/verb violations. For lexically marked violations on reflexives, P600 was elicited by stimuli in both the LVF and RVF; for morphologically marked violations on verbs, P600 was elicited only by RVF stimuli. These data suggest that both hemispheres can process lexically marked pronoun agreement violations, and do so in a similar fashion. Morphologically marked subject/verb agreement errors, however, showed a distinct LH advantage.

1. Introduction

Since Broca's 19th century report on the importance of the left hemisphere for speech production (Broca, 1965), language processing has been considered the paradigmatic case of a lateralized cognitive function in which the left hemisphere (LH) dominates, and the right (RH) plays a subordinate, and relatively minor role (Harrington, 1987, p. 75). However, more recent evidence from neuropsychological, metabolic, and electrophysiological studies of both normal and brain-damaged individuals has led to the current consensus that many aspects of language processing involve both hemispheres (Beeman and Chiarello, 1998), especially processing at the phonological (Hickok and Poeppel, 2007) and semantic (Federmeier and Kutas, 1999) levels of representation. In fact, there are some linguistic abilities for which the RH is considered to be dominant. This includes certain aspects of prosody, such as processing intonation contours (Behrens, 1989; Ross and Mesulam, 1979) and at least some aspects of discourse analysis (Brownell et al., 1983, 1995) such as the interpretation of one-line jokes (Coulson and Williams, 2005; Coulson and Wu, 2005). Nonetheless, the view that syntactic processing is strictly a LH function remains largely unchanged.

Skepticism regarding the RH capacity for grammatical processing is somewhat unwarranted, however, as very few studies have addressed this issue. Moreover, those that have done so suggest the RH has at least some syntactic processing ability (see Murasugi and Schneiderman, 2005, for a review). For example, in a classic study on this topic, Schneiderman and Saddy (1988) examined the performance of right brain damaged (RBD), left brain damaged (LBD), and non-brain-damaged (NBD) patients on two tasks requiring syntactic analysis. In both tasks, patients were asked to insert a given word into a sentence to form a new, grammatical sentence. For example, patients were tasked with inserting "wool" into "She brought the sweater that was mended." In this so-called non-shift item, it is possible to insert the word while maintaining the original analysis of the sentence (viz. "She brought the wool sweater that was mended.") Schneiderman and Saddy also tested so-called shift items, in which insertion of the word (e.g., "daughter") in the sentence ("Cindy saw her take his drink") required participants to partially reanalyze the structure of the initial sentence. That is, whereas the "her" in the initial sentence functions as the agent of the drink-taking event, the "her" in the revised sentence ("Cindy saw her daughter take his drink") serves to modify a different agent of the drink-taking event (Cindy's daughter). RBD patients did quite well on the non-shift insertion task, outscoring their LBD counterparts, consistent with the

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claim that the intact left hemisphere subserves grammatical processing. In contrast, on the shift insertion task (requiring role reassignment of a word), the LBD group actually outscored the RBD group. These data argue for the syntactic competence of the RH, and suggest that the two hemispheres might make somewhat different contributions to syntactic processing.

Further support for the claim that the RH performs some syntactic analysis comes from the commissurotomy literature. In particular, Zaidel (1983b) reports results from two adult split brain patients suggesting that the isolated RH may process subject/verb grammatical number agreement when it is signaled lexically (using an auxiliary, such as "is" or "are": the cat is eating/the cats are eating) but not when signaled morphologically (by the presence or absence of the third person singular simple present tense inflection "s": the cat eats/the cats eat). In contrast, isolated LH performance showed little difference between the two. Zaidel (1990) suggests that the RH finds certain linguistic categories easier to process than others, and proposes a hierarchy of ease of processing from lexical items (easiest) to morphological constructions to grammatical categories (case, number, gender, tense), with the most difficult being syntactic structures such as predication and complementation. However, Zaidel's (1990) model of RH syntactic competence is based on a small number of split-brain patients and may not generalize to the intact brain. Here we use the divided visual field paradigm in healthy adults to address Zaidel's (1990) prediction that the RH is more sensitive to grammatical information marked lexically (that is, it is signaled by an entire word) than morphologically (that is, it is signaled by meaningful unit within a word, such as the 'pre-'in 'prefix' or the 's' in 'dogs').

Apart from its celebrated use in commissurotomy patients (Gazzaniga and Hillyard, 1971; Gazzaniga and Sperry, 1967), the visual half-field paradigm also allows investigation of the RH's ability to process syntax using neurologically intact individuals. In this paradigm, stimuli are presented in either the right visual field (RVF) or the left (LVF), resulting in the initial stimulation of only the contralateral hemisphere. Research suggests that, even in neurologically intact individuals, half-field presentation results in the increased participation of the contralateral hemisphere in the processing of the stimulus (Hellige, 1983; Zaidel, 1983a). Differences in performance as a function of visual field thus allow inferences as to whether both hemispheres typically contribute to the processing of a given sort of stimulus, and, if so, whether there are differences in each hemisphere's contribution (Chiarello, 1991).

Although most research using the visual half-field paradigm has targeted hemispheric differences in semantic processing, there is at least one prior study investigating syntactic processing in neurotypical individuals. Liu et al. (1999) used the visual half-field paradigm to elucidate the role of each hemisphere in grammatical priming. Using three-word noun phrase stimuli, they found that ungrammatical cues delayed recognition of the target words presented to either hemisphere. These data were interpreted as supporting the idea that both hemispheres are sensitive to number agreement. Findings reported by Liu et al. (1999) are not in keeping with Zaidel (1990) claim that the RH is not sensitive to morphologically marked number agreement. However, it is not clear whether the processing done by participants with noun phrase stimuli is the same as that which would be done with natural language. Liu et al.'s findings might reflect task induced strategies rather than normal sentence processing mechanisms.

1.1. The present study

The present study used the visual half-field paradigm with healthy adults to investigate the capabilities of each hemisphere for a relatively simple syntactic process: grammatical number agreement. To do so we asked participants to read sentences and make judgments as to their grammaticality. For each sentence, the grammaticality or ungrammaticality of the sentence depended on a critical word which was presented in either the left visual field (LVF), the right visual field (RVF), or centrally. In order to assess the claim that the RH is more sensitive to syntactic information marked lexically than morphologically, we employed two different kinds of sentences. In our "reflexive" condition, number agreement between a reflexive pronoun and its antecedent was signaled lexically ("The grateful niece asked herself/*themselves how she could repay her aunt"). In our subject/verb condition, number agreement between a subject and a verb was signaled morphologically ("Industrial scientists develop/*develops many new products"). In experiments 1 and 2, the dependent variables were accuracy and reaction times for speeded grammaticality judgments. On this task, sensitivity to number agreement would be signaled by faster and more accurate responses to grammatical than ungrammatical sentences. Hemispheric differences in grammatical processing capability would be expected to show up as interactions between grammaticality and visual field (VF) of presentation, with larger grammaticality effects in one VF than the other. If the RH is indeed more sensitive to lexically than morphologically conveyed information, we might expect to observe greater evidence for hemispheric differences in the processing of the subject/verb than the reflexive sentences.

In experiment 3 we combined the visual half-field paradigm with the recording of event-related brain potentials (ERPs) in order to examine how lateralizing the critical words in either the left VF or the right affected the brain's real time processing of these stimuli. Concurrent recording of ERPs allows the investigator both to gauge how well VF presentation results in the participation of the contralateral hemisphere in stimulus processing (see, for example, Coulson et al., 2005), and to examine how VF presentation changes the brain response to the experimental manipulation (e.g., Federmeier and Kutas, 1999). If VF presentation impacts the size of an experimental effect on an ERP component, for example, we might infer that one hemisphere is more sensitive to the experimental variable than the other (see, for example, Coulson and Williams, 2005). Alternatively, VF presentation might result in experimental effects on different ERP components, suggestive of qualitative processing differences between the hemispheres (see, for example, Huang et al., 2010). If, however, VF presentation only impacted the onset latency of experimental ERP effects, it would suggest that stimuli are processed by the dominant hemisphere, and that VF presentation serves only to – alternately – speed up or delay their delivery.

The linguistic materials used in the present study were the same as those used in an ERP study reported by Kemmer et al. (2004) in which all materials were presented centrally. Kemmer et al. (2004) found that relative to syntactically well-formed control sentences, both sorts of grammatical number violations elicited a sustained centro-parietal positivity evident between 500 and 800 ms after word onset (P600). These data were in keeping with reports across a number of different languages that grammatical number violations, be they subject/verb or reflexive pronoun/antecedent grammatical number agreement or other violations, elicit a P600 component (English: Coulson et al., 1998; Osterhout et al., 1996; Osterhout and Mobley, 1995; Dutch: Hagoort and Brown, 2000; Hagoort et al., 1993; Vos et al., 2001; German: Münte et al., 1997). Sensitivity to the grammaticality of these materials might be expected to be manifest in a P600 effect. Quantitative hemispheric differences in sensitivity to grammaticality would be suggested by larger grammaticality effects with presentation to one VF over the other (e.g. larger P600 effects with presentation in the RVF/LH). Alternatively, if VF presentation resulted in grammaticality effects on different components of the ERP, it would signal qualitative differences in grammatical processing across the hemispheres.

2. Experiment 1

2.1. Methods

All procedures were approved by the Institutional Review Board at the University of California, San Diego, and were therefore performed