Inducing agrammatic profiles in normals

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Abstract

The selective vulnerability of morphology in agrammatic aphasia is often interpreted as evidence that closed-class items reside in a particular part of the brain (i.e., Broca's area); thus, damage to a part of the language processor maps onto behavior in a transparent fashion. We propose that the selective vulnerability of grammatical morphemes in receptive processing may be the result of decrements in overall processing capacity, and not the result of a selective lesion. We demonstrate agrammatic profiles in healthy adults who have their processing capacity diminished by engaging in a secondary task during testing. Our results suggest that this selective profile does not necessarily indicate the existence of a distinct sub-system specialized for the implicated aspects of syntax, but rather may be due to the vulnerability of these forms in the face of global resource diminution, at least in grammaticality judgment.

Introduction

Many researchers have argued that the selective vulnerability of particular aspects of grammar consequent to brain damage directly reveals the functional and (by extension) neuroanatomical organization of language; thus, the mapping from surface etiology to underlying architecture is relatively straightforward. If subjects have difficulty with a particular syntactic form, then we can postulate that the cognitive system has some sort of module (Fodor, 1983) which performs this operation. In arguing for the transparency hypothesis, Caramazza (1986) cites the selectivity of certain neurological dysfunctions (e.g., Warrington & Shallice, 1984; Hart, Berndt, & Caramazza, 1985). Agrammatic aphasia has been used as support for a model of brain function wherein Broca's area is responsible for those aspects of grammar implicated in the agrammatic syndrome.

Thus, the traditional clinical view of the syndrome was of a "central syntactic deficit" (Caramazza & Zurif, 1976; Caplan, 1981; Caramazza & Berndt, 1985) in which syntactic knowledge is *lost*, affecting both production and comprehension. However, later research indicated that agrammatics can make grammaticality judgments with above-chance accuracy, including many of the same sentence types that present serious problems for comprehension (Linebarger, Schwartz, & Saffran, 1983; Wulfeck, 1987; Shankweiler, Crain, Gorrell, & Tuller, 1989; Wulfeck & Bates, 1991). This finding challenges the central syntactic deficit or "loss of knowledge" account of agrammatic symptoms. The problem is very simple: How can a patient who has lost his syntactic knowledge make accurate judgments of grammaticality, the *sine qua non* of modern linguistic theory? Other problems for central agrammatism come from case studies of patients who display expressive agrammatism but no apparent comprehensive deficit (Kolk, van Grunsven, & Guper, 1982; Miceli, Mazzucchi, Menn, & Goodglass, 1983; Kolk & van Grunsven, 1984; Naeser, Helm-Estabrooks, Haas, Auerbach, & Levine, 1984; Nespoulous, Dordain, Perron, Ska, Bub, Caplan, et al., 1988; MacWhinney, Osmán-Sági, & Slobin, 1991), as well as reports of individuals and groups of patients who display receptive agrammatism but no corresponding expressive deficit (Caramazza, Basili, Koller, & Berndt, 1981; Caplan, 1985; Bates, Friederici, & Wulfeck, 1987a; Bates, Friederici, & Wulfeck, 1987b; Smith & Bates, 1987). Taken together, these various lines of evidence lead to a model of agrammatism in which impaired access and processing operate over a preserved knowledge base (Friederici, 1988; Bates, Wulfeck, & MacWhinney, 1991; Prather, Shapiro, Zurif, & Swinney, 1991; Wulfeck & Bates, 1991).

A number of investigators have offered a more restricted account of agrammatism called the "closed-class hypothesis" (Kean, 1979; Bradley, Garrett, & Zurif, 1980; Zurif & Grodzinsky, 1983; Friederici & Graetz, 1984). This proposal differs from initial views of agrammatism in two respects. First, the syndrome is restricted to the use of closed-class forms (inflections and function words), with sparing of word order. This partitioning of the grammar can also explain why agrammatic patients produce substitution and omission errors on function words and inflections, while preserving the order in which both open and closed-class items are expressed (that is, patients rarely make errors like "Dog the" for "The dog", or "ing-walk" for "walking"). Second, most researchers working within this framework have adopted the assumption that knowledge of closed-class elements (i.e. grammatical competence) is preserved in agrammatic patients; the deficit is now viewed as a problem with the access and use of closed-class elements in real time (i.e. grammatical performance—see, for example, Friederici, 1988; Garrett, 1992; Prather, Shapiro, Zurif & Swinney, 1991). But the assumption of a privileged and transparent relationship between the closed-class deficit and the tissue surrounding Broca's area is preserved within this new, more restricted account of agrammatism.

Yet there are caveats to hold in mind, both about the data—the assumption of the selective vulnerability of morphology—and about the assumptions to be drawn from these data—that damage to Broca's area is damage to the "closed-class box" of the brain. There are, for example, problems inherent in assuming that selective vulnerability of morphology—to whatever extent it holds true—must only result from selective damage to some "closed-class box". Data exist which point to a possible alternative explanation: that global impairments can result in selective, specific, and seemingly modular deficits.

Agrammatism in non-agrammatic patients

Bates and her colleagues have reported evidence for task profiles similar to that of agrammatics in a variety of non-agrammatic patient populations, using the "sentence interpretation" (SI) task, in which subjects are given a sentence and instructed to indicate the agent (Bates et al., 1987a). The subjects of main interest are Italian-speaking Broca's, anomics, older neurological patient controls, older non-neurological patient controls from the orthopedic ward, and younger controls.

Agreement had a very strong effect for younger controls. When the verb agreed with the first noun only, the first noun was almost always chosen as the actor, while when it agreed with the second noun only, the first noun was almost never chosen as the actor. The Broca's—as expected—were found to be impaired in their use of morphology on the SI task, with word order and semantic cues displaying the normal Italian profile. When the verb agreed with the first noun only, the first noun was chosen as the actor only somewhat above chance (about 67%), while when it agreed with the second noun the first noun was chosen only somewhat below chance (about 36%). When the Broca's were compared to the anomics, the older neurological controls, and the older non-neurological controls in three separate analyses of variance, in all three cases there were no significant interactions with the group factor and no significant main effects of group. Although the older patient controls do appear to be in between the Broca's and the younger controls, the group effect was contributed mainly by the younger controls. In comparing just the three control groups (neurological, non-neurological, and younger), the group × agreement interaction strongly favors the younger controls. In German, performing a similar comparison of young controls and older non-neurological patients found a similar group × agreement interaction favoring the younger controls. Thus, the older German controls were like the German Broca's tested in the same study. The German Broca's, like the Italian Broca's, showed less reliance on agreement morphology than younger controls in their language (with, in the German case, a compensatory reliance upon word order). Results showing similar profiles in comparing Broca's and anomics in Serbo-Croatian have also been reported (Smith & Bates, 1987).

Inducing agrammatism in normals: King and Just (1991) investigated the differences between high- and low-verbal-capacity subjects (assessed using the reading span task of Daneman & Carpenter, 1980) in comprehension of relative clause sentences, both with and without a concurrent memory load task. They compared subject-relative sentences, where the subject of the main clause is also the subject of the relative clause, with object-relative sentences, where the subject of the main clause is the object of the relative clause. Object-relative sentences, which are also harder for aphasics, showed greater vulnerability to a concurrent memory task then did subject-relative sentences. In addition, low-verbal-capacity subjects were poorer on object relatives than high-verbal-capacity subjects. As King and Just point out, low-span subjects are not globally less accurate, but they are particularly poor on the more computationally demanding object-relative sentences.

Miyake, Carpenter, & Just (in press) performed a similar experiment in the visual modality, where cognitive stress was induced by having the words presented at a "fast" rate (120 msecs/word). If severity of the simulated aphasic deficit is taken to be a conjoint function of span and rate of presentation, the interaction of severity of "deficit" with the complexity of the sentence type produces profiles quite similar to that of aphasics with similar test materials. Further, individual groups, created by cluster analysis of the data, differed in ways that could not be accounted for strictly as a function of sentence complexity and severity of deficit, in a manner similar to aphasics on the analogous Caplan, et al. task (Caplan, Baker, & Dehaut, 1985). Thus, aphasics may not represent a sharp break from normal processing, but may merely be at the far end of a continuum that includes both high, medium, and low normal processors.

Kilborn (1991) investigated the effects of a low-level noise mask on the SI task for both German- and English-speaking normals. In the no-noise condition, the English speakers' agent-choice strategies were heavily driven by word order, while the German speakers relied heavily on morphology and semantics. In the noise condition, the English speakers' agent-choice strategies were unaffected, remaining heavily driven by word order. The German speakers' agent-choice was affected, as they displayed less use of morphology and more reliance upon word order than in the no-noise condition, similar to the profiles displayed by German Broca's in the SI task (Bates et al., 1987a, see above).

The Current Experiment

If our claim that receptive agrammatism is in some cases due to the effects of global stress and not to damage to some particular "closed-class" module, then it should be possible to induce behavior consonant with receptive agrammatism in normal subjects by diminishing working-memory capacity. Agrammatics are more sensitive to violations of syntax (i.e., in the case of the grammaticality judgment task, transposition errors) than morphology (i.e., omission and agreement errors; Wulfeck and Bates, 1991). This same difference occurs in their production, in that omission and agreement errors are common in aphasic speech, while word order violations such as "dog the" and morpheme order violations such as "ing-walk" are rare (Bates et al., 1991). This symmetry may come about because the same aspects of the processor implicated in the receptive deficit are also responsible for self-monitoring.

With this in mind, we designed our stimuli to test these same contrasts. We presented subjects with auditory sentences containing one of three different error types: TRANSPOSITION errors (e.g., "She is selling books" ⇒ "She selling * is books"), OMISSION errors (e.g., "She selling * books") or AGREEMENT errors (e.g., "She are * selling books."). These stimuli were quite similar to those used in an earlier grammaticality judgment study (Blackwell, Bates, & Fisher, 1993) with normals in the visual domain (see also the Wulfeck & Bates, 1991 auditory grammaticality judgment study). One group hears these sentences in a baseline, single-task condition, the others are exposed to a simultaneous memory-load task, at varying levels of difficulty. We predicted that this memory-load manipulation would not cause an equal decrement in accuracy across all error types, but that errors would be differentially affected in a profile that resembles the patterns of vulnerability displayed by agrammatic patients. Specifically, agreement errors would be most vulnerable, followed by errors of omission, with the best performance displayed on errors of transposition.

TO SUMMARIZE OUR PREDICTIONS FOR PERFORMANCE BY NORMAL SUBJECTS UNDER STRESS: (1) Accuracy to transposition errors will be less affected by the stress manipulation than will omission and agreement errors; (2) This effect will be focused in errors that occur early in the sentence, while late errors will either not show the effect or will show it in a dilute form.

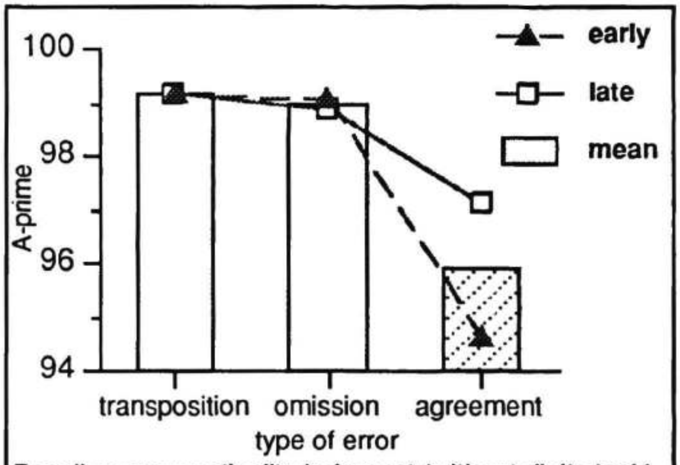
Subjects: Subjects were 112 U.C. San Diego students who participated in the experiment for course credit. All subjects stated that they were native speakers of English and right-handed. Other subjects who were not within two standard deviations of the mean on the various dependent variables were dropped.

Grammaticality Judgment Stimuli: Stimuli for the grammaticality judgment task include a total of 168 sentences: 84 ungrammatical target sentences, 40 grammatical control sentences matched for length and grammatical structure, and 44 distractors (22 grammatical and 22 ungrammatical). The design of the experiment is focused on the ungrammatical targets, which vary in the part of speech involved in the error (auxiliary vs. determiner), the position of the error within the sentence (early vs. late), and the kind of violation created from a common pool of grammatical types (i.e. errors of omission, agreement and transposition). The ungrammatical target sentences fall within a $2 \times 2 \times 3$ design (with error type, error location, and part of speech as within-subjects variables). For each of these ungrammatical sentences, subjects also see a grammatical control sentence matched for length and grammatical structure. To keep the length of the experiment within reasonable bounds, some of these grammatical sentences were used as controls for more than one particular ungrammatical sentence. Sentences were randomly pulled from lists of sentences of different structure types. Because omission, agreement and transposition errors were all created from the same basic sentence types, it can be argued that these stimuli represent a set of minimal contrasts.

Method

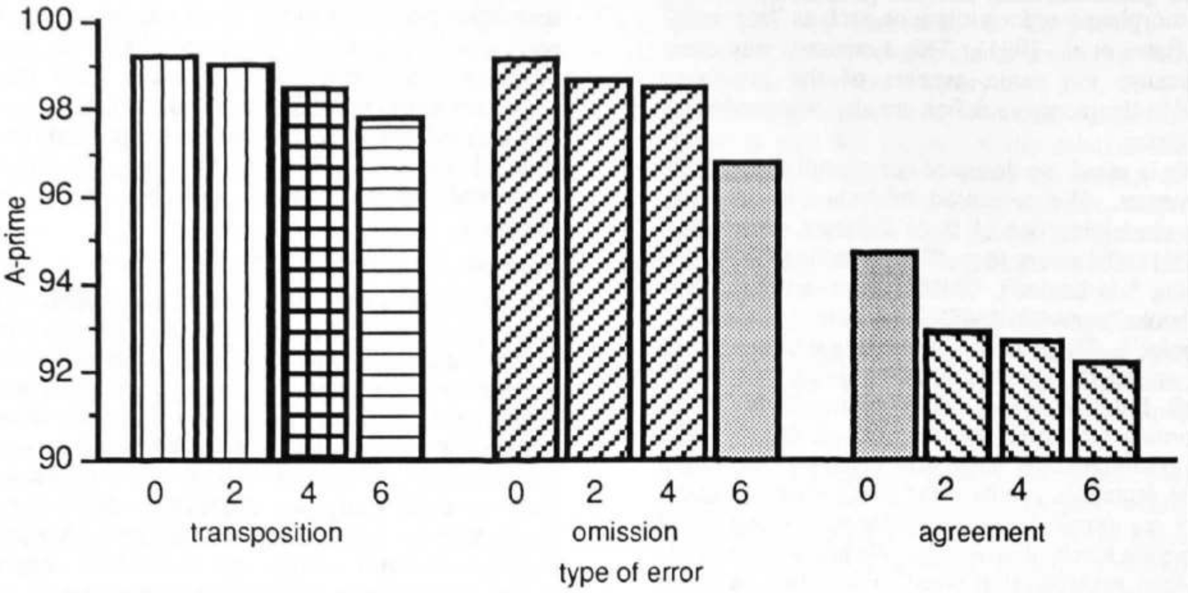
The experiment imposes a secondary task, in this case keeping a series of digits in memory. Subjects listen to a sentence and are instructed to judge the grammaticality of the sentence, pressing the appropriate key ("good" or "bad") as soon as they make their decision—even if the sentence is still running. In the digits condition, subjects see either two, four, or six "target" digits on the screen in front of them (only one number of digits per group, throughout the experiment). Immediately after the to-be-memorized digit string, an individual sentence is presented auditorily. After the sentence is over and they have made their grammaticality judgment, they then see another series of digits (the same number as in the target set), and are asked to decide whether this string is the "same" or "different" from the sequence presented before the sentence. In cases of a mismatch, the pre-sentence and post-sentence digit strings only differ by one number. Thus, in the three different digit conditions (two, four or six numbers), all subjects are forced to keep unrelated and arbitrary material in memory while they are making their grammaticality judgment.

Digit load (0, 2, 4 or 6 digits) was treated as a between-subjects variable. The various linguistic manipulations are all within-subject variables (error type—agreement, omission and transposition; part of speech—auxiliary vs. determiner; location of the error—early vs. late in the sentence).



Baseline grammaticality judgment (without digits task)

Figure 1



A-prime to early errors: by type and digit load. Bars sharing internal lines of the same orientation are not significantly different. These comparisons are within-type only.

Figure 2

Results

Baseline performance profile (no dual task): Subject sensitivity to error type was transposition = omission > agreement (see Figure 1). For the location × error type interaction, the pattern was transposition = omission > late agreement > early agreement. For the part of speech × error type interaction, the pattern was transposition = omission > auxiliary agreement > determiner agreement. Thus, even under normal conditions we found agreement errors to be particularly vulnerable, especially early agreement and determiner agreement.

Stressed performance profile (dual task): Profiles of sensitivity under cognitive stress were much as predicted: transposition > omission > agreement, seen in early errors only (see Figure 2). Early agreement errors showed an immediate accuracy drop at 2 digits, early omission errors at 6 digits, and early transposition errors showed a much smaller drop than omission errors at 6 digits. In other words, the three error types differ in their degree of vulnerability, a conclusion that is supported by performance in the baseline condition and by the clear differences that we observe in the "breaking point" when each item type is subjected to stress. This is the most important finding in the current experiment, demonstrating a clear link between the error profiles shown by agrammatic aphasics (in both comprehension and production) and the vulnerability profile displayed by normals under different degrees of cognitive overload. However, we must also note that the digit task had no effect upon late errors. It seems that the build-up of information across the course of the sentence is sufficient to "buffer" normal listeners against the effects of stress.

There is no evidence for a direct trade-off between the judgment and digit tasks. That is, subjects were not poorer at agreement and omission errors because (for some reason) they chose to do better at the digit task for those particular item types. This fact bolsters our confidence in use of the digit task to simulate the effects of a cognitive resource reduction.

All of our effects interacted with part of speech, which means that it is misleading to talk about "error types" as homogeneous categories. In both the baseline and dual task conditions, auxiliary errors were detected with greater accuracy than determiner errors; this difference interacted with the selective vulnerability of agreement errors (i.e., while both auxiliary agreement and determiner agreement errors were selectively vulnerable, determiner agreement errors showed a greater vulnerability than auxiliary agreement).

This part-of-speech effect was also reflected in performance on the digit load task, where subjects were *better* at holding the digits in memory when the stimuli were *auxiliaries* than when they were determiners. The same superiority of auxiliaries over determiners was found in the visual domain for grammaticality judgment (Blackwell et al., 1993). Wulfeck & Bates (1991) and Wulfeck, Bates, and Capasso (1991) have also reported superiority of auxiliary over determiner errors in auditory grammaticality judgment in normals. Those authors suggest this difference may be because sentence-level errors (i.e., auxiliary verb agreement) may be more structurally important than phrase-level errors (i.e., agreement of the determiner with its noun).

Why selective vulnerability?

This research adds to the growing body of evidence for the selective vulnerability of morphology, both in patient populations and in normals under conditions of diminished resources (see also Kilborn, 1991). Restricting ourselves to the current experiment for the moment, what makes agreement errors—and, to a lesser extent, omission errors—comparatively vulnerable?

The Competition Model: One possible explanation arises from the framework of the Competition Model (MacWhinney & Bates, 1989), designed to explain language acquisition and performance under real-time conditions and in a manner compatible with connectionist models of language processing (e.g., Elman, 1990; Elman, 1991). Constructs in this model include cue validity—the usefulness or informational value of a cue—and cue cost, the amount of resource (cognitive or otherwise) needed to use the cue (e.g., the more salient a cue the less costly). The Competition Model predicts that in normal acquisition the processor comes to tune itself more to those cues which have higher validity. In a language such as English, word order is a nearly deterministic cue to agenthood (i.e., in a noun-verb-noun sentence subjects almost invariably choose the first noun as agent). In Italian, word order is more free to vary, while verbs carry a greater load of morphological marking, and so agent choice is much more driven by verbal-agreement marking (Bates & MacWhinney, 1989).

The Competition Model predicts that in situations of resource diminution—such as in our experiment, and as in, we claim, receptive agrammatism—the vulnerability of a cue is proportional to its validity or information content. In a strict word order language such as English, sensitivity will show the pattern transposition > agreement, as we found here. In a language such as Italian, where agreement morphology is much more important than word order in determining agenthood, we would expect the opposite pattern of agreement > transposition. While this profile is consistent with findings in Italian, it is overlaid with the crosslinguistic finding that morphology is selectively vulnerable compared to word order.

In conclusion

What makes these particular error types—agreement errors and, to a lesser extent, omission errors—vulnerable? Does it have to do with the form of the information they carry (cue cost) or the amount or type of information that they carry—both are possibilities we have suggested—or are other factors at work, such as frequency of appearance during learning, neighborhood density, or memory constraints? There are a variety of angles of attack with which to pursue these questions, some of which we are currently engaged in within our laboratory. For example, one might carry out similar investigations of stressed grammaticality judgment across different languages, where these factors are different (e.g., languages in which agreement carries less information than in English, or where agreement cues are more salient). Another approach is to train subjects in small artificial language experiments where these factors can be manipulated directly (e.g., salience of a particular cue, information carried by that cue). Each approach, of course, has both strengths and weaknesses. We believe, however, that both approaches taken together should provide sizable insight into the issue.

Thus, although the underlying etiology of this selective vulnerability remains to be fully mapped, we have nonetheless demonstrated a definite problem with the transparency assumption: selective dissociations needn't always reflect selective disruptions of mental/neural architecture. *Apparent* damage to a "syntax module" may be due to the particular vulnerability of those aspects of syntax implicated.

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