

Temporal perception: A key to understanding language

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Abstract: Although Grodzinsky's target article has merit, it neglects the importance of neural mechanisms underlying language functions. We present results from our clinical studies on different levels of temporal information processing in aphasic patients and briefly review the existing data on neurobiology of language to cast new light on the main thesis of the target article.

Grodzinsky's target article provides a fresh approach to the cerebral representation of language. He argues that most human linguistic abilities are not located in the Broca's area, which for more than a century was believed to be a major centre associated with language production and syntactic processing. His hypothesis originates from a linguistic perspective only, however, and neglects neuronal processes. An important question arising from this article is: What neuronal mechanisms underlie the described functions?

A growing body of evidence suggests that temporal information processing controls many aspects of human behaviour, including language. Experimental studies using a variety of techniques and subject populations (e.g., Fitch et al. 1997) have consistently demonstrated that the superiority of the left hemisphere for the processing of verbal information may reflect a more primary specialisation for processing temporal cues, of which human speech is one example. Moreover, some language disorders in children and adults are associated with timing impairments.

On the basis of a hierarchical model of time perception (Pöppel 1994; 1997) we reinterpret the merits of this target article. Three different temporal ranges seem to be crucial for language, namely, about 2–3 sec, 200–300 msec, and 30–40 msec, corresponding respectively to the duration of phrases, syllables, and phonemes in fluent speech. In our clinical studies we found that temporal perception in aphasics is selectively affected at these three levels, depending on the localisation of lesion and existing disfluency patterns (van Steinbüchel et al. 1999).

The level of approximately 3 seconds was assessed by measuring temporal integration (TI). Experimental evidence (Pöppel 1978) suggests that sequences of events are automatically linked together into a perceptual gestalt. This binding process is pre-mantic (thus, independent of concrete events) and defines a "working platform" for mental activity. Using the subjective accentuation paradigm (Szelag 1997), we tested the extent of such TI in patients with precentral or postcentral lesions, either to the left hemisphere (resulting in nonfluent or fluent aphasia), or to the right hemisphere (without aphasia). While listening to metronome beats, patients were asked to accentuate mentally every *x*-th beat and create an individual rhythmic pattern. The extent of temporal integration was defined as the duration of the perceptual units comprised of such subjectively grouped beats. Broca's aphasics behaved differently from all other patient groups and acquired a new strategy because of the lesion, that is, they relied less on automatic TI and more on mental counting (Szelag et al. 1997). They had deficits in the binding operations that probably underlie not only the ability to construct full-fledged tree structures in production (i.e., effortful, nonfluent speech) but also their antecedents in comprehension, which need to integrate and hold the information for up to a few seconds. This hypothesis is supported by section 4 of the target article, which implies that some highly structured syntactic abilities are located in the anterior language area.

Grodzinsky also reports prominent failures on structures containing transformational operations and the deletion of all traces

of movement from syntactic representation in Broca's aphasics (sects. 2.1 and 2.2). It also seems that timing disorders in the domain of about 200–300 msec, corresponding to syllable processing, may be crucial for these comprehensibility deficits. We observed these disorders in self-paced (personal) finger tapping tasks. Patients with left hemisphere injury and Broca's or Wernicke's aphasia had significantly slower tapping fluency than other brain-damaged patient groups (von Steinbüchel et al. 1999).

On the other hand, a level of approximately 30 msec was assessed by measuring the auditory order threshold (OT), defined as the minimum time interval required to identify the temporal order of two successively presented clicks. This temporal range is associated with the perception of succession and phonemic hearing; and has been demonstrated to be basic in reaction time tasks and other high-speed temporal demands (Pöppel 1970; 1997). Patients with left hemisphere postcentral lesions, suffering from Wernicke's aphasia, showed prolonged OT, demonstrating important deficits in temporal processing at this high-frequency level, with impaired detection of single phonemes and lexicon in comprehension; Broca's aphasics were unaffected. These relationships are in agreement with Grodzinsky's thesis that semantic abilities are unaffected following lesions to Broca's area because phonemic hearing is preserved (sects. 1.1 and 1.2).

These observations support the conclusion that specific left hemisphere lesions selectively damage temporal mechanisms critical to the processing of both verbal and nonverbal information within a time frame of approximately 2 to 3 sec, 300 msec or 30 to 40 msec. Moreover, some areas of the left hemisphere play a more important role in temporal processing than others. We postulate that a disruption of timing mechanisms leads to the phonological and/or syntactic disorders commonly observed in aphasic patients. From the evidence briefly reviewed here, it can be seen that the linguistic abilities considered in Grodzinsky's article are governed by the central timing processor. With this in mind, we think that the target article's focus on the patients' linguistic skill in isolation, without any analysis of its neural substrate, cannot give a complete image of language organisation in the brain. Timing is essential to language use and different "neural clocks" underlie the machinery of comprehension and production.

What is special about Broca's area?

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Abstract: We discuss problematic theoretical and empirical issues and consider alternative explanations for Grodzinsky's hypotheses regarding receptive and expressive syntactic mechanisms in agrammatic aphasia. We also explore his claims pertaining to domain-specificity and neuroanatomical localization.

Grodzinsky has presented an impressive range of evidence from aphasia in support of the view that Broca's area and surrounding structures (hereafter referred to as "Broca's region") underlie receptive and expressive syntactic mechanisms. His endeavor to ground his hypotheses in linguistic theory is particularly valuable. Here we discuss a number of problematic theoretical and empirical issues related to his claims.

A syntactic role for Broca's region? Receptive mechanisms. First we address theoretical issues. In the syntactic framework assumed by Grodzinsky, certain constraints apply to all traces (the Empty Category Principle), whereas others distinguish not only between X⁰- and XP-traces, but also between two types of XP traces (Chomsky 1981; 1986; Rizzi 1990). Grodzinsky's theoretical motivation for implicating Broca's region in the former dis-

tion, but not the latter, is unclear. One principled difference is that XP but not X^0 traces are assigned thematic roles. However, Grodzinsky rejects the view that the receptive impairment concerns the mediating function of traces in thematic-role assignment (also see Grodzinsky & Finkel 1998). More generally, syntactic theory has shifted away from the concept of traces as syntactic objects in their own right or even as notational devices (Chomsky 1995a), further undermining the theoretical basis of positing a neurological deficit specific to traces.

Second, we turn to empirical issues. The arguments that Grodzinsky presents in support of the Trace Deletion Hypothesis (TDH) rely crucially on a three-way distinction between aphasics' performance at, below, or above chance. However, in a number of cases the level at which aphasics perform is not the one predicted by the TDH. English object-gap relative clauses and Japanese object scrambling are two examples. If subjects are assigned a thematic role through the mediation of a trace (the VP-Internal Subject hypothesis assumed by Grodzinsky), the grammatical assignment of an Agent role to the subject should be precluded in such structures. Thus the subject should not enter into thematic competition with the object (which should get the Agent role by the default strategy), resulting in below-chance performance and not the reported chance performance. Chinese subject-gap relatives are another example. Here, the object gets the grammatically assigned role of Theme. The subject should not compete for this role (unless the default strategy is modified so that non-first NPs get the Theme role), so the observed chance performance would be unexpected. If thematic-role assignment to objects is also trace-mediated (Chomsky 1995a), the object could not be assigned a thematic role grammatically, and should be assigned an Agent role by default, given its linear position as the first NP. This would result in below-chance performance in Chinese object-relatives. Additional sentence types problematic for the TDH are discussed by Beretta et al. (1999), Berndt and Caramazza (1999), and others.

Third, there may be alternative explanations. Grodzinsky discusses only briefly working memory and speed of processing deficits, both of which have been proposed to explain receptive agrammatism (see Kolk 1998). Both explanations warrant further examination: Broca's area has been linked strongly to working memory (Fiez et al. 1996b; Smith & Jonides 1997), and also to fast temporal processing (Fiez et al. 1995). Importantly, reports of dissociations between receptive syntax and working memory (Caplan & Waters 1999) are consistent with the view that different frontal regions may subserve different types of working memory (Smith & Jonides 1997).

Expressive mechanisms. We address theoretical issues first. Unlike the dichotomies between lexical versus functional, or Comp(lementizer)-related versus Infl(ection)-related projections, there is no clear theoretical basis to Grodzinsky's proposed categorical distinction between Tense and Agreement. Moreover, it has been argued that the relative order of Tense and Agreement is crosslinguistically parameterized (e.g., Ouhalla 1991); the order in English is posited to be opposite to that which Grodzinsky adopts for Hebrew, with AgrS (the projection licensing subject-verb agreement) higher than Tense (Chomsky 1993). Thus, impaired Tense and intact Agreement would not be expected in both English and Hebrew, contrary to Grodzinsky's claims.

Empirical issues are also problematic. The data are not consistent with a Tense/Agreement categorical distinction. First, Tense itself can be spared in agrammatism, whereas higher projections are impaired (see Hagiwara 1995). Second, agrammatics can show a graded impairment, with increasingly worse performance at higher projections. For example, Ullman et al. (in press) report decreasing production rates of verbal inflection at increasingly higher levels in the syntactic hierarchy (see also data presented in Hagiwara 1995).

Finally, there appear to be alternative explanations. Hagiwara (1995) has proposed that agrammatics' grammar allows convergence (i.e., successful computation) at lower functional projec-

tions, because such structures are less costly from a global economy perspective (i.e., comparing different syntactic derivations; Chomsky 1993). Ullman et al. (in press) argue that graded impairments of functional projections can be explained by deficits of concatenation and/or movement. Because functional categories are assumed to be concatenated and to trigger verb movement stepwise into hierarchical structures, from lower to higher categories (Chomsky 1993), such deficits should yield a greater likelihood of successful computation of lower than higher categories.

Relation between receptive and expressive mechanisms. We have two concerns with the receptive and expressive deficits posited to underlie agrammatism: the lack of an independent factor, linguistic or neuropsychological, unifying the two, and the highly specific nature of the deficits. Impaired computation could arise from deficits of linguistic knowledge (competence) or processing (performance). Although linguistic knowledge is often thought of as highly modular (Chomsky 1981; 1995a), it is generally thought to underlie the computation of structures in both the receptive and expressive modalities (e.g., Crain & Fodor 1989). Thus if linguistic knowledge is affected, the deficit should similarly affect both modalities, contrary to Grodzinsky's claims. Indeed, greater deficits in higher than lower functional categories are found in *receptive* as well as expressive agrammatism (Hagiwara 1995). In contrast, although different *processing* mechanisms may be posited for receptive and expressive modalities, they do not normally employ highly specific components, such as a module whose only function is to construct solely those parts of the syntactic tree at and above Tense.

Is Broca's region domain-specific? It is not clear whether Grodzinsky is suggesting that all of Broca's region is dedicated to language, or whether, within this region, there exist specific structures dedicated to language. The first case is clearly false: Evidence suggests that Broca's area underlies motor functions (see Rizzolatti & Arbib 1998). The second case is also problematic. To demonstrate domain-specificity, one must show that *no* nonlanguage functions are subserved by the neural material or cognitive component in question. At the very least it should be demonstrated that those nonlanguage functions most likely to explain a set of linguistic impairments do not co-occur with those impairments. It is therefore puzzling that Grodzinsky concentrates on mathematical combinatorial skills, given that he explicitly posits that Broca's region does not subserve the "basic combinatorial capacities necessary for language processing" (Abstract).

Grodzinsky also claims that Broca's region plays a restricted role within language, subserving only the two hypothesized syntactic functions. However, Broca's aphasics are more impaired at producing, reading, and even judging regularly inflected than irregularly inflected forms (Badecker & Caramazza 1987; Marin et al. 1976; Ullman et al. 1997; in press). This morphological affixation deficit in both expression and reception cannot be explained by Grodzinsky's hypothesized syntactic dysfunctions. Finally, there is also substantial evidence that Broca's area plays a role in phonology (see Demonet et al. 1996) and in lexical search or retrieval (see Buckner & Tulving 1995).

Anatomical localization. Grodzinsky's effort to implicate Broca's region alone in the hypothesized syntactic functions is hampered by problems of patient selection. Conclusions regarding the function of Broca's region would be less problematic if patients were selected *solely* on the basis of their lesions, which should be limited to those structures. However, many of the Broca's aphasics on which Grodzinsky bases his claims also have lesions outside Broca's region, or, even worse, have no reported lesions to this region at all (e.g., Friedmann & Grodzinsky 1997; Grodzinsky 1989; Grodzinsky & Finkel 1998). For additional discussion on patient selection, see Berndt & Caramazza 1999; Grodzinsky et al. 1999.) More generally, chronic Broca's aphasia is also associated with damage to left parietal regions (Alexander 1997). Grodzinsky points out that Wernicke's aphasics' failures in syntactic comprehension are inconsistent and varied. Perhaps this variability of impairments correlates with Wernicke's aphasics'

variability in damage to inferior parietal regions (Alexander 1997). Indeed, conduction aphasia is associated with both left inferior parietal damage (Alexander 1997) and syntactic processing deficits (see Caramazza et al. 1981). It may be that left inferior parietal regions, in concert with left frontal structures, underlie grammatical processing, in a working memory role (Smith & Jonides 1997), or perhaps as a repository of grammatical knowledge.

Conclusion. We have argued that a number of Grodzinsky's specific claims are problematic, and should therefore be weakened or modified. Nevertheless, we strongly support his program relating language deficits to linguistic theory, and believe that such an approach will prove crucial to our understanding of both the neurobiology and structure of language.

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The need to consider additional variables when summarizing agrammatism research

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Abstract: Throughout the history of aphasiology, researchers have identified important premorbid and stroke-related predictors of linguistic performance. Although Grodzinsky discusses some of these variables, exclusion of other variables could lead to unnecessary experimental error and erroneous conclusions. Aspects to consider include sources of experimental bias, premorbid differences, nonlinguistic roles of the frontal regions, and comparison of normal and aphasic performance.

Grodzinsky identifies common factors of linguistic performance across languages and tasks, reviewing data from various studies. He considers the variables of diagnostic label and lesion source when collecting results of studies, and his analysis of spoken output takes into account differences among languages' canonical sentence order and morphosyntax. Important aspects of how the studies' original data were obtained have not been taken into account, however. These aspects can be categorized as sources of nonsampling and sampling bias, premorbid differences, nonlinguistic roles of the frontal cortical regions, and comparative data about neurologically normal performance. A brief review of these variables not considered in Grodzinsky's article suggests that combining the results of agrammatism studies could lead to erroneous conclusions.

In applied social research methods, there are three components that comprise experimental error, or the difference between the results of a sample and the truth about a population. Nonsampling bias includes errors in defining the population of interest. Sampling bias consists of inequalities caused by unequal or disproportionate sampling from subgroups of the population under consideration. Sampling error is the expected set of differences between the sample and the population, creating the need for inferential statistical methods (Henry 1998). In agrammatism research, only sampling error has been addressed fully (Bates et al. 1991).

Nonsampling bias, specifically errors in defining the population, can result from problems with subject classification (Henry 1998). It has been noted that classification systems within standard aphasia batteries have imperfect classification and diagnostic abilities, leading to overlap among categories (Clark et al. 1979; Rao 1994). Also, different aphasia batteries can give different labels for the same subject's performance (Caplan 1987b). As a result, selecting subjects only according to a diagnosis of Broca's aphasia from various batteries could lead to possible differences

in subject selection criteria across studies (Bates et al. 1991).

An unknown degree of sampling bias could result from three problems with subject selection methods used in agrammatism research. First, we know little about the nature and prevalence of documented subgroups of Broca's aphasia, described by either lesion site or performance (Love & Webb 1992; Sundet & Engvik 1985). Second, we do not know how subjects were selected out of the available pool of Broca's aphasics for each study (Bates et al. 1991). Third, we do not know much about the relationship of lesion site and diagnostic label to the naturally occurring category or population of impairment underlying diagnoses of Broca's aphasia, anterior aphasia, nonfluent aphasia, or agrammatism, making it difficult currently to sample equally or proportionately (Anderson 1991; Bates et al. 1991; Menn et al. 1995).

In addition, premorbid differences may contribute in unknown ways to differences in patient performance. Interpersonal sociological factors such as age, educational level, number of languages spoken, and socioeconomic background, in addition to their interactions and relationships with performance variables, are considered increasingly important to modern aphasia research (Bates et al. 1991; Coffey et al. 1998; Menn et al. 1995). Also, various unknown or inadequately researched cohort effects are thought to result from generational or historical changes within the population of interest (Glenn 1977). These changes may be significantly associated with subtle but important changes in the epidemiology of stroke and its clinical profile in the population. Furthermore, aspects of hemispheric specialization and aspects of memory are two areas of research that have contributed greatly to understanding individual, normal neurolinguistic, and psycholinguistic differences (Dean 1985; Engle 1996).

Also, focusing almost exclusively on grammatical performance and comprehension may lead to a disregard of interactions with nonlinguistic roles of the frontal lobe. In addition to the syntactic-semantic aspects of frontal lesions, deficits in oral-motor abilities and working memory also result from lesions to frontal regions (Brookshire 1997; Damasio & Anderson 1993; Darley et al. 1975). Likewise, direct effects of brain damage may be confounded by the concurrent use of compensatory abilities and strategies (Blackwell & Bates 1995; Menn et al. 1995).

Furthermore, Grodzinsky's approach has de-emphasized comparative information on how neurologically normal control subjects perform on similar tasks. Various studies using neurologically normal speakers of a language have demonstrated the existence of occasional discrepancies between grammatical competence and performance and the existence of normal performance errors on neurolinguistic measures (Cook & Newson 1996; Lezak 1995). Consequently, there is no assurance that the tasks given to subjects with aphasia are ones that all neurologically normal, competent speakers would always perform "perfectly" or ideally. As a result, overall experimental error may result from comparing aphasics' performance with ideal syntactic-semantic output, rather than comparing normal and aphasic performance to determine their similarities and differences.

In summary, the type of impairment variously labeled and diagnosed as Broca's aphasia, anterior aphasia, nonfluent aphasia, or agrammatism is apparently a natural category of impairment with unique qualities, but the multidisciplinary field of aphasiology is far from discovering its nature. Grodzinsky's research and that of others have been invaluable in determining aspects of the nature of this type of aphasia and the differences between its syntactic-semantic performance pattern and ideal performance. However, the inclusion of additional, previously identified variables and results of other lines of research would improve the knowledge about this category of aphasia.