Agrammatic Aphasia and the Hierarchy Complexity Hypothesis

Running Head: Agrammatic Aphasia

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ABSTRACT

Anterior aphasia is associated with left frontal brain damage and “agrammatism”: syntactic impairments in both expressive and receptive language, and the omission and substitution of inflections (e.g., past-tense) and function words (e.g., auxiliaries, determiners). We offer an explicit neurocognitive and inguistic account of the impairment of aspects of syntax in agrammatism. We assume a widely-adopted linguistic framework in which syntactic computations involve the construction of hierarchies through sequential operations of combining linguistic categories such as Noun and Determiner, or Verb, Tense and Agreement. We propose the Hierarchy Complexity Hypothesis, which posits that a single deficit— one affecting the building of hierarchical syntactic structures — can account for a range of impairments in agrammatism (and possibly in other populations as well), including impairments in the use of closed-class items. We further propose that the deficit results from damage to left frontal/basal-ganglia circuits that also underlie motor sequencing. We examined the inflectional errors of anterior and posterior aphasics in expressive language (production and reading) and receptive language (judgment). As predicted, anterior but not posterior aphasics had greater difficulty with inflections dependent upon more complex hierarchical structures, both between and within individual subjects.

KEY WORDS: language, agrammatism, syntax, declarative/procedural model

Linguistic categories provide a principled way to distinguish between classes of linguistic elements that exhibit similar behavior and have similar distributions. A fundamental distinction between two types of category — open- and closed-class — has emerged from both theoretical and experimental studies of language. Open-class categories like Noun, Verb, or Adjective admit as many new members ("content" words) as can be remembered. Closed-class categories are relatively small, fixed inventories of items, including "function" words (e.g., determiners such as *the*, *every*) and bound inflectional morphemes (e.g., representing tense and agreement, as in *–ed* or *–s*). Closed-class items play an important grammatical role. Their orders with respect to each other and to open-class categories, are core properties that all theories of syntax must capture. Closed-class items are generally phonologically shorter and less salient (e.g., often unstressed), semantically more abstract, and of higher frequency than open-class items (Caplan, 1987; Caplan, 1992; Gleason and Ratner, 1998; Pinker, 1994).

The representational, psychological and neurobiological underpinnings of the two types of categories have been the subject of intensive investigation. Numerous dissociations between the two types of categories have been demonstrated. Cognitively intact adults show distinct electrophysiological Event-Related Potential (ERP) signatures for the two classes of items (Neville et al., 1992; Segalowitz and Chevalier, 1998). Compared to native-speaking adults, young children and adult second language learners tend to rely more on open- than closed-class words (Ellis, 1997; Gleason, 2000). Similarly, closed-class words and morphemes appear to be disproportionately impaired in some brain disorders, including hereditary developmental disorders affecting language (i.e., Specific Language Impairment) (Leonard, 1998; Ullman and Gopnik, 1999) and Parkinson's disease (Illes, 1989; Ullman et al., 1997). In other disorders, such as Alzheimer's disease, open-class words are more affected (e.g., Schwartz et al., 1979; Ullman et al., 1997). It has been argued that such open-/closed-class dissociations support the view that the two types of categories depend on at least partly distinct neurocognitive correlates (Leonard, 1998; Platzack, 1990; Radford, 1990). However, it has also been claimed that the dissociations may be explained by continuous rather than dichotomous differences between the two types of words and morphemes, such as in their phonological characteristics, frequencies or semantic content (Joanisse and Seidenberg, 1998; Leonard, 1998).

One of the most striking dissociations between closed- and open-class words is found in aphasia — that is, adult-onset language impairments caused by brain damage (e.g., from stroke). There are at least two fundamental categories of aphasia (Alexander, 1997; Damasio, 1992; Goodglass, 1993). Anterior aphasia is associated with damage to left frontal regions, in particular Broca's area (generally referring to portions of the inferior frontal gyrus, including the cytoarchitectonic Brodmann's areas 44 and/or 45) and nearby cortex, the basal ganglia, and portions of inferior parietal cortex (Alexander, 1997; Damasio, 1992). Characteristic of anterior aphasia is "agrammatism": syntactic and morphological impairments in expressive and receptive language, including the omission or substitution of closed-class elements. Anterior aphasics' use of open-class words tends to be relatively spared. In contrast, posterior aphasia is associated with damage to left temporal and temporo-parietal regions, and impairments in the production, reading, and recognition of the sounds and meanings of content words. Posterior aphasics tend to produce syntactically well-structured sentences, and not to omit closed-class morphemes (Alexander, 1997; Damasio, 1992; Goodglass, 1993; Kolk, 1998).

A variety of accounts of the closed-/open-class dissociations in anterior and posterior aphasia have been proposed, most of which have focussed on agrammatism (Caplan, 1980; Caplan, 1987; Goodglass, 1993; Kolk, 1998). The relative impairment of closed-class items in agrammatic aphasia has been explained with a variety of accounts motivated by linguistic theory: deficits of the closed-class categories (de Bleser and Bayer, 1991; Grodzinsky, 1984; Grodzinsky, 1986; Grodzinsky, 1990; Ouhalla, 1993), or of their processing (Bradley et al., 1980); as well as phonological (Kean, 1980) or morphological (Goodenough et al., 1977; Goodglass and Berko, 1960; Lapointe, 1983) deficits motivated by theoretical distinctions between closed and open class items. It has also been proposed that the dissociations can be explained by more general processing limitations (Goodglass, 1973; Kolk, 1998), or by non-categorical differences between the items, such as in their semantic content (Joanisse and Seidenberg, 1999).

It has been difficult to provide a unified account, from the perspectives of both grammatical theory and cognitive neuroscience (Miceli et al., 1989), of the closed-/open-class dissociations in aphasia — let alone of the wider pattern of syntactic impairment and sparing across the different types of aphasia. Here we propose a novel hypothesis, which is motivated by findings from both linguistic theory and cognitive neuroscience.

Functional Categories and Linguistic Theory

We focus on one widely-adopted and explicit theoretical perspective: the Principles and Parameters framework, including its recent extensions such as Minimalism (Chomsky, 1995). Within this framework categories are taken from the lexicon as input to the computational system, which generates *structured representations* (which themselves serve as input to the articulatory-perceptual and conceptual systems). For example, the relationship between a verb and its argument (e.g., *eat* and *cheese*) is constrained by syntactic structure: abstract nodes that correspond to the verb and the noun are combined, creating a structured representation for the phrase *eat cheese.* The head of each phrase (i.e., its obligatory member) determines its syntactic category, e.g., Verbs head V(erb) P(hrase)s, Nouns head N(oun) P(hrase)s, and so on. The category of the head determines in what larger syntactic structure this phrase can be embedded and what other phrases can be embedded in it.

Early work in the Principles and Parameters framework focused largely on *lexical categories* (i.e., open-class categories), such as Noun, Verb and Adjective, and their phrases (i.e., NP, VP and AP) (Jackendoff, 1977). Subsequent work has extended the theory to *functional* categories. Thus it has been proposed that Determiners (e.g., *the*, *every*) head their own phrases (DPs) (Abney, 1987). Similarly, INFL(ection) (tense/agreement) and Complementizers (e.g. sentence-introducing elements like *that*, *whether*) have both been integrated into the theory. C(omplementizer) projects a CP, which in turn takes an IP — INFL Phrase — as its complement (Chomsky, 1986). It has also been argued that INFL actually constitutes two separate functional categories, T(ense) and Agr(reement), each of which thus project an independent phrase (TP and AgrP) (Chomsky, 1991; Pollock, 1989).

More recent work has seen an enormous expansion of the proposed inventory of functional categories (Cinque, 1999; Rizzi, 1997). This has raised a number of questions, especially regarding the number and kinds of functional categories, and in what (hierarchical) orders they occur, within and across individual languages (see Lightfoot and Hornstein, 1994; Ouhalla, 1991).

Hierarchical syntactic structures are built as a sequence of combinations (operations of *Merge*) of lexical and functional categories. In particular, each lexical category is combined (through Merge) with a particular functional category, followed by the sequential merge of other functional categories, one after the other, from sub-ordinate (lower) to super-ordinate (higher) categories (e.g., Chomsky, 1995). Thus a lexical projection such as NP is merged with the functional category D to form a DP like *the cheese*. Similarly, a (lexical) VP is merged with a (functional) I, and the created IP in turn is merged with a (functional) C to form a clause (a CP). In general, as much structure is built as is necessary to compose all items drawn from the lexicon for a particular derivation. (A top-down composition of hierarchical syntactic structures has also been proposed within Minimalism (Phillips, 1996). However, like the more widely assumed bottom-up approach, it also posits that lexical projections are most deeply embedded (i.e., lowest) in the syntactic hierarchy and that they are dominated by the same number of functional projections arranged in the same order. In other words, whether a clause is built top-down or bottom-up, the top-down order of projections is CP, IP, and VP.) The presence of any given functional category in a syntactic phrase necessitates the presence of the projections of all lower functional categories and the relevant lexical category (Grimshaw, 1991).

Hierarchies of Functional Categories and Agrammatic Aphasia

Although many studies have focused on the dichotomy between closed- and open-class categories, others have examined more subtle distinctions. In particular, a number of investigations have examined distinctions *within* closed-class items and their functional categories (Jakubowicz and Nash, 2001; Leonard, 1998; Platzack, 2001). In agrammatic aphasia, it has long been noticed that not all closed-class items are uniformly impaired (Caplan, 1987; Kolk, 1998). A number of recent proposals have implicated the hierarchy of functional categories in this pattern of impairment. Each of these studies has interpreted its data within the Principles and Parameters framework. Each has argued that, in agrammatic aphasics, computations dependent upon higher functional categories are more impaired than those dependent upon lower categories, resulting in certain inflections and function words being more compromised than others.

Hagiwara (1995) bases her claims on data from Japanese agrammatic aphasia, as well as on previously reported data from agrammatic aphasia in Romance and Germanic languages. In spontaneous speech from four Japanese agrammatic aphasics, some complementizers were omitted, but apparently negation words were spared. On a grammaticality judgment task, two agrammatic aphasics performed better with negation and tense than with the CP-dependent *wh*-words and complementizers. On the same task a mildly impaired aphasic performed well on all of these functional elements, whereas three severely impaired patients performed poorly on all.

Hagiwara proposes that, in the group of agrammatic aphasics who showed the unequal pattern of impairments, lower functional projections such as T(ense)P and Neg(ation)P were resistant to damage, whereas higher projections, such as Agreement-for-Subject Phrase (AgrSP) and C(omplementizer)P appeared to be unavailable. Specifically, she posits that whereas the grammar of normal adults necessitates "convergence" (Chomsky, 1993) (i.e., successful computation) at the highest functional projection (e.g., the CP for the clause), the agrammatic aphasic's grammar allows convergence at lower functional projections (e.g., at Negation). Hagiwara argues that different subjects may converge at different functional heads, explaining *between*-subject differences in severity. However, her proposal is stated in a way that is incompatible with graded (probabilistic) success by individual agrammatics. Rather, an all-or-nothing pattern of performance *within* subjects is predicted. That is, a given patient should be equally (and presumably completely) impaired at all functional categories above this point of convergence, and completely spared below it. As will be discussed below, this is contrary to the expectations of our own hypothesis.

Hagiwara's proposal that higher functional categories are more impaired clearly captures certain broad patterns in her findings. Unfortunately, aspects of the data advanced in support of her proposal are somewhat problematic. In the judgment task, performance was not perfect at sentences dependent upon the supposedly completely spared functional categories. Because data from normal control subjects were not reported, it is impossible to determine whether or not the aphasics were completely unimpaired, as predicted. Additionally, there was a consistent pattern of better performance on judging sentences dependent upon one of the supposedly spared categories (Negation) than the other (Tense), suggesting a graded performance within subjects, contrary to her predictions. Indeed, because Negation is claimed to be lower than Tense (see Hagiwara, 1995), this pattern conforms exactly to the graded pattern predicted by the hypothesis presented in the present paper.

Friedmann and Grodzinsky have reported data from a number of Hebrew and Arabic agrammatic patients (Friedmann and Grodzinsky, 1994; Friedmann and Grodzinsky, 1997; Friedmann, 2001; Friedmann, in press; Grodzinsky, 2000). The data include spontaneous speech transcripts as well as experimental results from elicitation, repetition, judgment and comprehension tasks. Several functional projections were probed, in particular, Agreement, Tense and Complementizer Phrases. The authors argue that the patients manifested impairments with Tense and Complementizer, but had completely spared Agreement. Moreover, it is claimed that the impairments were found only in expressive language, and not in receptive language (i.e., not in judgment or comprehension tasks). Following the assumptions regarding clause structure advanced by Pollock (Pollock, 1989), they adopt a representation in which the top-down ordering of categories in the clause is CP-TP-AgrP-NegP-VP at least in these languages (see also Ouhalla, 1991). They argue that the patients' impairments are explained by the tree being "pruned" below the Tense Phrase, but above the Agreement Phrase. To characterize such deficits as potentially differing in severity across patients, Friedmann & Grodzinsky further suggest that the pruning site in the hierarchy can differ among patients, being higher with greater impairment. Crucially, the "Tree Pruning Hypothesis" does not allow for deficits to be graded across functional categories *within* individual patients. Rather, the expected outcome is an impairment that equally affects all functional projections above the site of pruning (presumably rendering them completely inaccessible), but completely spares all functional projections below the particular site.

Friedmann & Grodzinsky's data do not show the all-or-nothing non-graded pattern. First, like Hagiwara's data, it is not clear that the supposedly spared functional categories are actually free from impairment. Data from normal control subjects were not statistically compared to the patient's data. Because the patients rarely achieved perfect performance on the conditions dependent upon the putatively spared categories, an impairment, albeit a lesser one than in the other conditions, may have gone undetected. Note that even perfect performance is not particularly meaningful in the context of perfect performance by control subjects, because this is consistent with a ceiling effect. Second, among the functional categories that are claimed to be impaired, the data did not appear to conform to the pattern of equally (and fully) dysfunctional projections that is predicted by the Tree Pruning Hypothesis. Virtually none of the conditions resulted in a complete failure. More importantly, the data suggested a graded impairment over the supposedly inaccessible functional projections, with higher projections being more difficult than lower projections *within subjects*. Thus of the 14 subjects reported by Friedmann (2001), 13 showed a graded pattern of worse performance at CP than (the lower) TP, (although, unfortunately, no statistical analyses of these differences are reported). This highly consistent pattern runs contrary to the prediction of the Tree Pruning Hypothesis that all functional categories above the pruning point should be equally (and fully) impaired. In contrast, the findings are expected by the hypothesis put forth in the present paper. The claim that the deficit is not found in receptive language is also problematic. First, receptive tasks are reported for only one (Friedmann and Grodzinsky, 1997) of the many patients that were tested. Second, even for this one patient, judgment was not completely spared. Third, the judgment data reported by Hagiwara (1995) run contrary to the claim that the computation of functional categories is spared in judgment tasks. Finally, the Tree Pruning Hypothesis is subject to various theoretical difficulties. Because these have been presented elsewhere (Grodzinsky, 2000; Ullman and Izvorski, 2000), we limit ourselves to the observation that the posited linguistic deficit is unmotivated by independent neuropsychological evidence. It is particularly difficult to accept that the often extensive brain damage associated with agramatic aphasia would result in such a specific impairment as to distinguish between two closely related linguistic projections whose independent status from each other is controversial even within the particular linguistic framework assumed (Chomsky, 1995; Iatridou, 1990).

The Hierarchy Complexity Hypothesis

The proposal put forth by Hagiwara and by Friedmann and Grodzinsky are groundbreaking and extremely important, in that they opened the way to interpreting aspects of agrammatism in terms of differential deficits in the hierarchy of functional categories. Here we follow this spirit, but propose a very different hypothesis to explain a range of language impairments in agrammatic aphasia including (but not limited to) those affecting inflection and function words. The Hierarchy Complexity Hypothesis (HCH) (also see Izvorski and Ullman, ; Izvorski and Ullman, 2000) posits that, because of the greater complexity of hierarchical structures required by higher categories (due to the larger number of categories below them), the *relative* height of a given category in the hierarchy predicts its severity of impairment. Linguistic forms dependent upon higher categories should be *probabilistically, not categorically*, more problematic than those dependent upon lower categories. Thus the HCH predicts a *graded* impairment not only between subjects, but also *within* subjects, in both expressive and receptive language. That is, within a given subject, the higher a functional category, the greater the difficulty in computing it. Although a number of deficits could in principle lead to this pattern, and are compatible with the HCH (see General Discussion), here we focus on a specific deficit which can explain much of the observed pattern of agrammatic impairments in a neuropsychologically principled way, integrating the linguistic manifestation of agrammatism with independent properties of the brain systems implicated in this aphasic syndrome.

We posit that agrammatic aphasia is associated with a deficit affecting the operation that combines elements into structures (i.e., Merge). Because more combination operations are required for building structures with higher functional projections (see above), these will be less likely to be successfully constructed than structures with only lower functional projections. Thus, the resulting impairment will not be all-or-nothing. The deficit affects the likelihood of a successful combination (i.e., of the Merge operation). Therefore a graded pattern *within* individual subjects is predicted, with linguistic forms (inflections or free function words) dependent upon higher projections more likely to be computed, in expressive and receptive language, than linguistic forms dependent only upon lower projections. Moreover, subjects with a greater deficit of the combinatorial operation should show more difficulty at computing a given syntactic hierarchy of projections than subjects whose facility at Merge is less affected.

This deficit is compatible with, and indeed is predicted by, previous neuropsychological and neurolinguistic theory and evidence. According to the Declarative/Procedural Model (Ullman, 2001a; Ullman, 2001b; Ullman et al., 1997), aspects of rule-governed combination, and structure-building in particular, involve a well-studied “procedural memory” brain system. This system has been implicated in learning new, and controlling well-established, motor and cognitive skills and habits, from simple motor acts to skilled game playing (Heilman et al., 1997; Schacter and Tulving, 1994; Squire and Knowlton, 2000). Learning and remembering these procedures is largely implicit. It has been argued that the procedural system is informationally encapsulated, having relatively little access to other mental systems. (Note that here the term 'procedural memory' is used to refer only to one particular brain memory system, not to all non-declarative or implicit memory system.) Procedural memory is rooted in portions of frontal cortex (including Broca’s area and Supplementary Motor Area), the basal ganglia, and parietal cortex. This system might be related to the dorsal visual stream (Goodale, 2000) and is important for learning or processing skills that involve action sequences (Willingham, 1998). The execution of these skills seems to be guided in real time by posterior parietal cortex, which is densely connected with frontal regions (Goodale, 2000). Similarly, the basal ganglia are also densely connected with frontal cortex. Basal ganglia circuits seem to be parallel and functionally segregated; each of them projects through the thalamus to a particular cortical region, largely in frontal cortex (Alexander et al., 1990).

In contrast, the mental dictionary (lexical memory) is posited to depend upon a distinct brain system, “declarative memory”, that is rooted in medial and neocortical temporal lobe structures and underlies the learning and use of non-linguistic fact and event knowledge. Multiple lines of evidence, from several languages, using a number of different methodologies support the view that aspects of grammar, and structure building in particular, depend upon on the procedural system, whereas lexical information is memorized in the declarative memory system (Ullman, 2001a; Ullman, 2001b; Ullman et al., 1997).

Of interest here, the model is relevant to aphasia. As discussed above, anterior aphasia is associated with damage to left frontal structures (particularly Broca's area and nearby cortex), the basal ganglia, and parietal regions. In addition to agrammatism, anterior aphasia is linked to impairments in the expression of motor skills (ideomotor apraxia) (Goodglass, 1993). The prediction that anterior aphasics tend to have grammatical structure-building problems has been examined in depth with investigations of morphology. In both expressive and receptive language, anterior aphasics are more impaired at computing regular morphological forms, which are posited to be built in real-time through the combination of their parts (e.g., *walk, -ed*), than irregular morphological forms, which must depend at least partially upon memorized representations (see Ullman, 2001b).

In contrast, posterior aphasia is associated not only with content word difficulties and relatively spared syntactic performance, but also with an absence of motor impairments (Alexander, 1997; Goodglass, 1993). As predicted by an absence of a structure-building deficit in morphology (but by the presence of lexical difficulties), posterior aphasics show the opposite pattern to anterior aphasics, having particular trouble with irregular morphology (Ullman et al., 1997; Ullman et al., in press).

According to the Declarative/Procedural Model, a structure-building deficit should be found across all grammatical domains. It is expected in syntactic as well as morphological structure building. This leads to the predictions of the Hierarchy Complexity Hypothesis that anterior aphasics should show an impairment computing functional categories, and that this impairment should be graded, with higher categories being more problematic than lower ones. In contrast, no such impairment of functional categories is expected in posterior aphasia.

THE STUDIES

As described above, previously reported evidence (Friedmann, 2001; Hagiwara, 1995) appears to support the HCH. Here we present a set of studies which directly tested its predictions, focusing on the computation of English verbal inflection.

As discussed above, in the linguistic framework we are assuming, inflection is intrinsically tied to combinatorial operations between lexical and functional categories. (We are necessarily glossing over many intricate issues in the licensing of inflection posited by the Principles and Parameters framework. Similarly, various approaches exist as to the exact interplay between syntax and morphology (see Borer, 1998).) The categories relevant for the computation of an inflected verb correspond to a structural description like that in the Figure. The most deeply embedded (i.e., lowest) projection in the syntactic structure is the lexical projection of VP, where verbal stems are inserted. Next, an Asp(ect) head, projecting to an AspP, is merged into the structure. Depending on its feature-content, Asp may be realized phonologically by an -*ing*-affix (in the progressive, or present participle, e.g., *writing*), by an -*en*-affix (in the perfect, or past, participle; e.g., *written*), or by a regular past participle *–ed* affix or non-affixal (i.e., irregular) past participial morphology (as in *sung*). (The discussion of Aspect is by necessity oversimplified. In theoretical linguistic research various Aspectual Projections have been posited. In particular, the licensing of perfect and progressive participles likely depends on two distinct AspPs, based on the fact that the two can be realized simultaneously, e.g., *John has been writing* (Iatridou et al., 2001).) Then, a T(ense) category with a particular tense feature, e.g., [past], is merged. It can be expressed phonologically through an affix or in an irregular form (as in *walked* or *dug*). The order of these functional projections can be explicitly reflected in a sentence such as *John was walking*, where the tensed auxiliary is in T, and the participle is in Asp. Importantly, even when the inflected verb is not a participle (e.g., *wrote*), it is generally assumed (Giorgi and Pianesi, 2001) that abstract features of Asp are present in the structure, and just not realized phonologically, although they are visible to the semantics. (In other languages, such as Slavic, aspectual features are overtly realized on tensed verbs and not just on participles.) Thus, a syntactic representation for a past tense form will include not only a VP and a TP, but also the AspP. Given this hierarchical arrangement of categories, different morphophonological realizations of a verb (e.g. *write, writing, written, wrote*) rely upon increasingly 'higher' categories in this hierarchy. The non-inflected (stem) form (e.g., *write*) instantiates the lexical category of V. The progressive and perfect participles (i.e., *writing* and *written*, respectively) are dependent upon the structure [V – Asp]. Finite forms such *wrote* necessitate yet more complex hierarchy [[[V – Asp] – T].

[Figure about here]

Additional functional projections are possible and have been proposed. Of particular relevance here is the category of Subject Agreement. The existence of a separate functional projection AgrP is controversial within linguistic theory (Chomsky, 1995; Iatridou, 1990). Nevertheless, syntactic theories that employ this projection generally agree that in English AgrSP (Agreement-for-Subject Phrase; see above) is merged higher than TP (Chomsky, 1993; Ouhalla, 1991). From this, however, we cannot necessarily conclude that a tensed form which expresses agreement overtly (e.g. *writes*) depends upon a higher projection than a tensed form which does not express agreement overtly (e.g., *wrote*), since it is often assumed that *wrote* carries abstract features for agreement, and thus it depends on this projection as well. In any case, and crucially for our purposes here, it is clear that any form dependent upon AgrSP relies on more instances of Merge than participial forms, which rely only on the (lower) Aspectual projection.

Interesting issues arise with respect to inflected words presented in isolation, outside the context of the sentence. Linguistic approaches to the syntax-morphology interface differ as to whether they implicate functional projections in the composition of such linguistic forms. According to some, inflected forms are composed pre-syntactically, in the lexicon, by mechanisms distinct from (though perhaps similar to) those of syntax. (Di Sciullo and Williams, 1987; Jensen, 1990). On this view, isolated forms with different inflections (e.g., *writing, written, wrote, writes*) should not depend upon different levels of functional categories, and therefore should not show the graded pattern of impairment in agrammatic aphasia predicted by the HCH. Another class of theories consider inflected forms to be the result of syntactic composition (Baker, 1988, Halle, 1993 #6882). On this view, as syntax builds the isolated inflected words, different morpho-phonological realizations of a verb (e.g. *writing, written, wrote, writes*) may rely upon increasingly higher categories in the syntactic hierarchy.

We examined verb inflection both in agrammatic anterior aphasia and in anomic posterior aphasia, in three tasks: the elicited production (generation) of past tense forms in sentence contexts; isolated reading of past tense forms; and judgment of past tense forms in sentence contexts. English past tense is appropriate to test our predictions as it allows the teasing apart of morphological, phonological and syntactic explanations for the aphasics' errors in a highly controlled way. It involves both affixal (e.g., *walk-walked*) and non-affixal (e.g., *sing-sang*) inflection. (We use the terms affixal and non-affixal to refer to the overt phonological realization of the past tense inflection, without presupposing a particular morphological theory.) It also involves inflected forms that are articulatorily more challenging and acoustically less salient (e.g., *kept, walked*) compared to others (e.g., *showed, bought, sang*). Importantly, the various inflected past tense forms have identical syntax, at least in a sentential context. If agrammatic aphasics only have problems with morphological affixation, then they should not be impaired on forms like *sang*. If the agrammatic impairment were due to the fact that affixes are phonologically less salient and often harder to pronounce than stems, forms such as *sang* should remain relatively unaffected, as they are identical in the relevant phonological aspects to *sing*. Finally, English past tense has been extensively studied from a variety of linguistic, psycholinguistic, developmental, and neuropsychological perspectives, including in aphasia (see Pinker, 1999; Ullman, 2001b).

The past tense production and judgment tasks aimed to examine the aphasics' performance at inflection in the context of a sentence (e.g., *Every day I verb-stem … Yesterday I* _*verb form*_ …). In the judgment task, both (correct) past tense and (incorrect) stem forms were presented in this past tense context, allowing us to test the judgment of a form dependent on a lower projection in a context requiring a higher one. The judgment task crucially allows us to test the prediction that anterior aphasics should have difficulty in receptive language. The production and reading tasks permit the examination of error types. Error forms dependent upon lower projections are expected to be easier to compute than those dependent upon higher projections. Thus we might expect more stem forms (e.g., *break*), which depend only upon the lexical projection VP, than participial forms (e.g., *breaking*, *broken*), which depend on a functional projection no higher than AspP, than –*s*-forms (*breaks*), which depend on the highest projection (see above).

METHOD

Subjects

The past tense production task was successfully completed by 2 anterior aphasics and 6 posterior aphasics. An additional 5 anterior aphasics were not able to perform the task. The past tense reading task was successfully completed by 9 anterior aphasics and 3 posterior aphasics. One additional anterior aphasic did not complete the task. All aphasic subjects were native speakers of American or Canadian English. All had suffered a left hemisphere stroke or resected aneurysm, and had no known right-hemisphere damage. All aphasic subjects were right-handed before their lesion onset. Aphasic subjects were classified as either anterior or posterior aphasic on the basis of clinical and behavioral data. All anterior aphasics had agrammatic speech, defined by reduced phrase length and reduced syntactic complexity. All had left frontal lesions, with or without extensions to temporal or temporo-parietal regions. Ten of the 11 anterior aphasics were diagnosed as Broca's aphasics, on the basis of the Boston Diagnostic Aphasia Exam (BDAE; Goodglass and Kaplan (1983)) or the Western Aphasia Battery (WAB; Kertesz (1982)); the remaining anterior aphasic did not receive a clinical classification. All posterior aphasics had word-finding difficulties (anomia). Lesion data were available for 7 of the 9 posterior aphasics; all seven suffered damage to left temporal or temporo-parietal structures, with little or no frontal involvement. The remaining two posterior aphasics were diagnosed with Wernicke's aphasia, which is associated with temporal and temporo-parietal lesions, with sparing of frontal cortex (Alexander, 1997; Damasio, 1992). Three of the 9 posterior aphasics were diagnosed as anomic aphasics, 3 as Wernicke's aphasics, and 3 did not receive a clinical classification. Several groups of neurologically unimpaired right-handed native English speakers served as control subjects. In the production task, 12 subjects served as age- and education-matched controls for the anterior aphasics, and 8 as controls for the posterior aphasics. In the reading task, 8 subjects served as age- and education-matched controls, for both aphasic groups. Forty undergraduates served as control subjects for all aphasics on the judgment task. Although they were younger than the aphasic subjects, their level of education (12 to 16 years) was similar to that of the four aphasic subjects (12, 14, 16, and 16 years). Details on all patients and control subjects can be found in Ullman et al. (in press). All subjects gave informed consent.

Materials

Past Tense Production. Analyses were based on 20 regular (e.g., *look-looked*) and 16 irregular verbs (e.g., *dig-dug*). Of the irregular verbs, 6 are likely –*t*-affixed, according to the theory of Distributed Morphology (Halle and Marantz, 1993): *bend-bent, make-made, think-thought, stand-stood, keep-kept, send-sent.* The remaining 10 were classified as non-affixed irregulars. Furthermore, 13 of the 16 irregular verbs have past-tenses which do not involve a consonant cluster in their coda: *swim-swam, dig-dug, swing-swung, cling-clung, wring-wrung, bite-bit, feed-fed, come-came, make-made, give-gave, think-thought, stand-stood, drive-drove*. The novel verbs consisted of 20 novel regular verbs (classified as such because their stems are not phonologically similar to the stems of any existing irregulars, and their expected pasts are therefore regular, e.g., *plag-plagged*) and 18 novel irregular verbs (whose stems are phonologically similar to the stems of existing irregulars, and whose possible past tense forms might therefore be either irregularized or regularized, e.g., *crive-crove/crived*, c.f. *drive-drove, jive-jived*). All verbs were presented in the context of two sentences: "Every day I *rob* a bank. Just like every day, yesterday I _____ a bank" (the "verb presentation sentence" and "past tense sentence", respectively).

Past Tense Reading. Items consistent of 34 past tense forms (17 regular item-matched to 17 irregulars). Twelve of the regular verbs had no word-final complex consonant cluster in their past tense forms: *flowed, viewed, weighed, slowed, owed, sighed, tied, stayed, died, prayed, tried, showed*. Eight of the irregular past-tenses were treated as non–*t*-affixed, (Halle and Marantz, 1993): *hid, strode, clung, swore, slid, drove, spoke, held*. Nine may be analyzed as involving –*t*-affixation in this framework: *lent, swept, fled, bought, spent, sent, kept, left, felt*. In addition, 9 of the irregular past-tense forms had no word-final complex consonant clusters (*hid, strode, clung, swore, fled, slid, bought, drove, spoke*), while the remaining 8 ended in a complex coda (e.g., *felt, kept*).

Past Tense Judgment. Subjects were presented with the same verbs as in the past tense production task. All verbs were presented in the context of two sentences. All verbs were presented twice, in a counterbalanced order, both times in the same sentence pair context. In one presentation the verb form in the past tense sentence was the correctly inflected past tense form, and in the other presentation the verb form was not correctly inflected. This incorrect form was the unmarked form for real and novel regular verbs (e.g., Just like every day, yesterday I *rob* a bank"). Additional details on all items on all three tasks may be found in Ullman et al. (in press).

Procedure

In each of the three tasks the items were pseudo-randomized to ensure that similar-sounding verb forms did not follow each other too closely. In each task, subjects received items in the same order. All sessions were audio-taped. During testing, a native English-speaking experimenter wrote down all responses. All analyses were carried out on the basis of the subjects' first response. In the past tense production task, the subject was asked to read each sentence pair out loud, filling in the missing word. If reading was laborious, both sentences were read by the experimenter. In the past tense reading task, the subject was asked to read the items out loud. Each word was printed on a single sheet of paper. A subset of the subjects were also asked to read out loud the stems of the 34 verbs, which were intermixed with the past tense items. In the past tense judgment task, aphasic subjects were asked to give numerical ratings according to how bad or good the verb in the second sentence sounded as a past tense of the verb in the first sentence. Anterior aphasic subject BMC was unable to follow this rating scheme, and was therefore given simpler instructions, being asked to say whether the form was acceptable or not ("yes" or "no"). . Control subjects read each sentence pair out loud; an experimenter read them aloud to the aphasic patients. Each sentence pair was printed on a single sheet of paper in large font. Additional details on procedure may be found in Ullman et al. (in press).

Response Coding: Past Tense Production and Reading Tasks. For novel regular verbs, only regularizations (*spuffed*) were counted as correct. For novel irregular verbs (*crive*) both regularized (*crived*) and irregularized (*crove,* cf. *drive-drove*, *dive-dove*) forms were correct. Errors were categorized into several types. Incorrect responses marked for past tense were coded as PAST MARKED ERRORS: over-regularizations (*digged*), -*ed*-suffixed irregulars (*dig-dugged*, *crive-croved*), multiply –*ed*-suffixed forms (*look-lookeded, crive-criveded*), over-irregularizations (*fling-flang*), incorrectly syllabified –*ed*-suffixed forms (*look-look-id*), and –*ed*-suffixed or irregularized substitutions (*stir-sterned*, *frink-freaked*, *feed-fled*) and distortions (*stoff-stroffed*, *drive-drovbe*). Other errors were UNMARKED (*look-look, crive-crive*), -*ING*-SUFFIXED (*bend-bending*), -*EN*-SUFFIXED (*bite-bitten*, *make-maken*, *play-playn*), -*S*-SUFFIXED (*show-shows*), UNMARKED SUBSTITUTIONS (*shrell-squeeze*, *strink-stroke*), –*ING*-SUFFIXED SUBSTITUTIONS (*cook-tooking*, *dig-sinking*), –*EN*-SUFFIXED SUBSTITUTIONS (*speak-smoken*), or –*S*-SUFFIXED SUBSTITUTIONS (*view-vows*). Remaining errors were classified as WORD SUBSTITUTIONS (non-verb based real words; *flow-flowers*), DISTORTIONS, OTHER or NO RESPONSE.

Study 1: Past Tense Production

Anterior Aphasia

The past tense production task was given to 7 agrammatic anterior aphasics. Only one of them, FCL, completed the task in its entirety. His lesion was circumscribed to left anterior structures, and did not impinge upon temporal or temporo-parietal regions. Another anterior aphasic, RBA, was able to perform the task for real but not novel verbs. RBA had less circumscribed lesions than FCL, extending from left frontal to left posterior regions.

FCL

Performance at past tense inflection. As predicted, FCL was impaired at inflecting verbs (Table 1). His overall success rate at past-tense inflection was significantly lower than that of the control subjects, over all verb types tested (see Methods; 28% vs. 95%; paired $t(73)=12.29$, $p<.0001$, over items; all p values are reported as two-tailed, unless otherwise indicated), over real (regular and irregular) verbs (42% vs. 97%; paired *t*(35)=6.561, *p*<.0001), and over novel verbs (16% vs. 93%; paired *t*(37)=11.821, *p*<.0001).

Alternative explanations to the HCH do not appear to account entirely for this pattern. First, FCL's impaired performance at past-tense production might be explained by poor performance only at regular verbs, due to a morphophonological problem with *–ed*-affixation (Ullman et al., 1997; Ullman et al., in press). However, his rate of producing past-tense forms on real irregular verbs was significantly lower than that of the control subjects (69% vs. 96%; paired *t*(15)=2.27, *p*=.038). Second, it has been claimed that certain irregular past-tense forms involve overt phonological affixation (Halle and Marantz, 1993). That is, many irregulars ending with –t (e.g., *kept, bent*) are claimed to be constructed by combining the stem with a *–t* affix (which is distinct from the *–d* [i.e., -*ed*] affix found on regular verbs). If this were the case, it could be argued that FCL's relative impairment at irregulars might be due entirely to such *–t*-affixed past-tenses, as a result of his morphophonological affixation impairment. We therefore separately examined a subset of 10 irregular verbs that arguably involve no *–t*-affixation (see Methods). FCL's performance on these irregulars was still worse, though not significantly, than his control subjects (80% vs. 96% paired *t*(9)=1.11, *p* = .30). Third, it might also be argued that FCL's unmarked (stems; e.g., *look*, *drive* errors on irregulars can be explained by problems with lexical memory. This is plausible, given that anterior aphasics often have difficulty retrieving (though not recognizing) words (Caplan, 1987; Goodglass, 1993). On this view, the stored irregular representations would not be retrieved successfully. However, virtually all of FCL's errors were unmarked forms or inflectional errors (see below), as predicted by the Hierarchy Complexity Hypothesis. Among the irregular verb items, he produced no paraphasias, no unrelated responses, no distortions, and had no failures to respond.

FCL's impairment at inflection was revealed not only by his low success rate but also by his failure to mark past tense on incorrect responses. Only one of his errors on real verbs and 4 on novel verbs (9% of his errors over all verb types) were past-marked: two irregularly inflected substitutions (*rush-ran*, *drite-swam*), and three *–ed*-suffixed distortions (*pob-plubbed, raff-traffled, plam-*

planned). In contrast, the majority of the control subjects' errors (56%) were past-marked: over-regularizations (e.g., *make-maked*), -*ed*-suffixed distortions and substitutions (e.g., *vask-vasted*, *steeze-stepped*), irregularly inflected substitutions (e.g., *cleed-clept*), over-irregularizations (e.g., *swing-swang*), and -*ed* -suffixed irregularizations (*strink-stranked*). In other words, even when they made an error, the control subjects still inflected their response according to the syntactic requirements of the presentation sentence, whereas FCL did not. The difference between FCL's and the control subjects' rate of past tense marking — that is, combining correct forms and incorrect but past-marked forms — was significant over all four verb types (35% vs. 98%; paired $t(73)=11.12$ $p<.0001$), over real verbs (44% vs. 99%, paired $t(35)=6.601$ $p<.0001$) and over novel verbs (26% vs. 97%, paired $t(37)= 9.279$ $p<.0001$).

<u>Pattern of inflectional errors.</u> The kinds of errors produced by FCL further strengthen the view that his impairment can be characterized in terms of the Hierarchy Complexity Hypothesis (Tables 1 and 2). Many of FCL's errors were unmarked forms (e.g., *dig-dig*). Over all verb types, these constituted 24% of his responses (34% of his errors), and were more or less evenly distributed between real verbs (22% of items; 38% of errors) and novel verbs (26% of items; 31% of errors). In comparison, the control subjects produced very few unmarked forms (only 2% of their responses). The difference between FCL's and the control subjects' response rates of unmarked forms was statistically significant, over all verb types (24% vs. 2%; paired $t(73)=4.46$ $p<.0001$), over real verbs (22% vs. 0.69%, paired $t(35)=3.12$ $p=.004$), and over novel verbs (26% vs. 2.41%, paired $t(37)=3.160$ $p=.003$).

Not only did the control subjects produce significantly fewer unmarked forms than FCL, but in addition, most of the unmarked forms that they did produce (11 out of 14 times) were forms ending in /d/ or /t/. Moreover, most of these stem forms are of novel verbs and are phonologically plausible regular novel past-tense forms: *cleed, prend* and *preed*: These can clearly be misinterpreted as past-marked (e.g., *pren-prenned*). In contrast, *none* of the many unmarked forms which FCL produced ended in /d/ or /t/, indicating that he was not producing unmarked forms as a result of inappropriate interpretation of the forms as being –*ed*-suffixed.

It could be argued that many of the unmarked forms produced by FCL are the result of articulatory difficulties. All of verb stems in the production task ended in a consonant. Thus their –*ed*-suffixed past tenses (e.g., *dropped, spuffed*) involve word-final consonant clusters that may be hard to articulate. The articulatory/phonological impairments typically found in anterior aphasics (Alexander, 1997; Goodglass, 1993) could therefore result in cluster simplification, yielding unmarked forms (*drop, spuff*). We examined FCL's performance on the 13 irregular verbs whose past tense does not involve a word-final consonant cluster (e.g., *swim-swam, stand-stood*; see Methods for full list). Even among these verbs he produced quite a few unmarked forms, whereas the control subjects produced none (15% vs. 0%). This suggests that an articulatory difficulty cannot explain all of his unmarked forms. Moreover, FCL did not make cluster simplification errors such as *keep-kep, bend-ben*, or *send-sen*, further undermining an articulatory (i.e., motor) and/or phonological explanation for his unmarked forms. The high rate of unmarked forms produced by FCL also cannot be (entirely) explained by the fact that the verb stem was presented to him and thus was very salient, and possibly still maintained in working memory (e.g., *Every day I rob a bank. Just like every day, yesterday I _____ a bank.*). Even when he made substitution errors, and thus did not repeat the presented stem, FCL predominantly produced unmarked forms: Sixty percent of his substitutions were stems (e.g., *shrell-squeeze*).

FCL produced many –*ing*-forms (18% of items; 25% of errors) and one –*en*-suffixed irregular (1% of items, 2% of errors). The combined rate of –*ing*- and –*en*-suffixed forms — that is, FCL's production rate of clearly participial forms — constituted 19% of items, and 26% of errors. Note that the percentages of past participial forms produced does not include forms which have identical past tense and past participial forms. Such past-tense/past-participial forms include all regulars and many irregulars (e.g., *walk-walked-walked, dig-dug-dug*). Therefore the percentages should be viewed as a lower bound of produced participial forms. (Conversely, the past-tense inflection rates discussed above should be viewed as an upper bound, since many of them may have been actual past participial forms.) FCL's production rate of participial forms (i.e., past participial and present participials combined) was significantly greater than zero (paired $t(73) = 3.94$, $p < .0001$, one-tailed;

in comparisons between production rates and zero, p-values are reported as one-tailed, because the production rates cannot be less than zero). Furthermore, FCL produced 3 forms in which he uttered the stem and then spelled the *–ing*-affix out loud (*vurn – i-n-g; prass – i-n-g; brop – i-n-g*). In comparison, FCL's control subjects produced no *–ing*- or *–en*-forms; compared to FCL, paired $t(73) = 3.94$, $p < .0001$). As predicted by the Hierarchy Complexity Hypothesis, FCL produced more unmarked than participial forms, though the difference was not significant (24% vs. 19%; paired $t(73) = 0.90$, $p = .373$). Neither FCL nor the control subjects produced any *–s*-suffixed forms.

RBA

Performance at past tense inflection. Because RBA was not able to perform the past tense production task for novel verbs, all analyses were carried out on real verbs only. His performance, like that of FCL, revealed the expected impairment at inflection (Table 1). His overall success rate on real verbs was significantly less than that of his control subjects (22% vs. 97%; paired $t(35)=10.525$ $p<.0001$, over items). This pattern also held for irregular verbs alone (25% vs. 96%; paired $t(15)=6.093$ $p<.0001$ over items). Similarly, on the subset of 10 irregulars which are posited to be non–*t*-affixed, RBA had a success rate of 30%, compared to subjects' 96% (paired $t(9) = 4.01$, $p = .003$).

Like FCL, RBA had a low rate not only of producing correct past tense forms, but also of marking errors for past tense. Only 21% of RBA's incorrect responses were past marked: over-regularizations (*digged*, *swinged*), an *–ed*-suffixed irregularization (*camed*), distortions (e.g., *mar-mwarred*), and a substitution (*chop-shot*). Adding those past marked errors to his correct responses on real verbs still yielded a rate of past marking significantly lower than that of the control subjects (39% vs. 99%; paired $t(35)=7.33$ $p<.0001$).

Pattern of inflectional errors. The majority of RBA's errors (Tables 1 and 2) were unmarked forms (42% of items; 54% of errors). RBA's rate of producing unmarked forms for real verbs was significantly higher than the control subjects' (42% vs. 0.7%, paired $t(35)=4.85$, $p<.0001$). Twelve out of his 15 unmarked responses (80%) were on verbs whose stems did not end in a /t/ or /d/, suggesting, just as in the case of FCL, that the reason for his production of unmarked forms was distinct from that of control subjects. Importantly, RBA produced many unmarked errors on the 13 irregular verbs whose past-tense forms do not end in a consonant cluster (54% vs. 0% for the control subjects, paired $t(12)=3.74$ $p=.003$). This argues against a purely articulatory or phonological explanation for his uninflected forms; that is, whereas cluster simplification may be at the heart of errors like (*cross-cross*), it cannot be the case that all of his unmarked errors are due to articulatory or phonological difficulties. Moreover, RBA did not produce forms like *sen* (for *sent*), or *ben* (for *bent*), did produce forms like *kept*, and generated the unmarked responses *stand* and *think*, articulating the consonant clusters, rather than the phonologically simpler past-tense forms *stood* and *thought.*

Like FCL, RBA also produced *–ing*-forms (6% of items, 7% of errors): both on the same verb as the one presented (e.g., *soar-soaring*) and on substituted verbs (e.g., *cook-tooking*). His production rate of *–ing*-forms (6%) was greater than zero, approaching statistical significance ($t(35)=1.435$, $p = .08$ one-tailed). Neither the control subjects, nor, as we shall see below, the posterior aphasics, produced any *–ing*-forms. RBA's production rate of *–ing*-forms was significantly lower than that of unmarked forms (paired $t(35) =3.65$, $p =.001$, as a percentage of items). He produced no *–en*- or *–s*-suffixed forms.

Anterior Aphasics as a Group

Together, FCL and RBA performed significantly worse than the control subjects, both on all real verbs (32% vs. 97% correct, paired $t(35) = 11.83$, $p < .0001$), and on irregulars alone (47% vs. 96%, paired $t(15) = 5.51$ $p<.0001$). They also performed significantly worse than the control subjects on the subset of non-affixed irregulars (55% vs. 96%, paired $t(9)=3.86$, $p=.004$) suggesting that they indeed have problems with inflection over and above any problems with affixation per se. Their errors had a very low rate of past tense inflection: on real verbs, 10% of their errors, compared with 64% for the control subjects. Their rate of past tense marking on real verbs (correct inflection plus past-tense-marked errors) was significantly lower than that of the control subjects (42% vs. 99%, paired $t(35) = 10.07$, $p <.0001$).

The two aphasics produced a high number of unmarked forms on real verb stimuli (32% of items; 47% of errors). Their rate of producing unmarked forms for real verbs was significantly higher than the control subjects' (32% vs. 0.7%, paired $t(35)=6.31$ $p<.0001$). The significant difference remains when irregular verbs are examined separately (28% vs. 0.5%, paired $t(15)=3.45$ $p<.01$), when the subset of irregulars with simple codas in their past tense forms is examined separately (35% vs. 0%, paired $t(12)=3.96$ $p = .002$), and also when the subset of non-affixed irregulars is examined alone (30% vs. 0%, paired $t(9)=2.71$ $p=.024$). The aphasics also produced more unmarked (32%) than –*ing*-forms (17%): paired $t(35) = 1.93$, $p = .062$.

FCL was less impaired than RBA at past tense inflection (42% vs. 32%). He also produced more past marked forms (correct past-tenses and past-marked errors combined, 76% vs. 39%), and produced fewer unmarked forms than RBA, both as percentage of items (22% vs. 42%), but importantly also as percentage of errors (38% vs. 54%). This is consistent with the predictions of the HCH that the severity of the impairment can vary across patients.

The anterior aphasics' performance patterns correspond to those expected by the Hierarchy Complexity Hypothesis. Both anterior aphasics exhibited problems with past tense inflection. This was apparent in their low rates of producing past-marked forms, both on correctly inflected forms and on errors. They were impaired at inflecting non–*t*-affixed as well as –*t*-affixed irregulars. Their errors were mostly unmarked forms, which were not entirely attributable to articulatory or phonological impairments, lexical retrieval impairments, or task-specific factors. They had significantly higher production rates of both unmarked and –*ing*-forms than control subjects. They showed the expected graded pattern of inflectional errors, with more unmarked forms than –*ing*-forms. RBA produced fewer past-tense inflected forms and more unmarked forms than FCL, indicating that the predicted inflectional patterns can vary in severity across patients.

[Table 1 about here]

[Table 2 about here]

Posterior Aphasia

The past tense production task was given to one posterior aphasic, JLU, whose lesion was circumscribed to temporal and temporo-parietal regions, as well as to five posterior aphasics whose lesions were less circumscribed, extending to frontal and/or basal ganglia structures. All posterior aphasics completed the task for real verbs. One posterior aphasic, JHA, could not perform the task for novel verbs.

JLU

Performance at past tense inflection. Unlike the anterior aphasics, JLU did not show an impairment at inflection (Table 1). Although he was more impaired than his control subjects at inflecting all verb types combined (77% vs. 96%; $t(73)=4.05$, $p=.0001$), and this pattern also held upon examination of all real verbs (78% vs. 99%; $t(35)=3.09$ $p=.004$) and all novel verbs (76% vs. 93%; $t(37)=2.62$, $p=.013$), he was crucially not significantly more impaired than the control subjects at inflecting regular verbs (e.g., *looked*; 90% vs. 99%; paired $t(19)=1.45$ $p=.164$) or novel regulars (e.g., *plagged*; 80% vs. 94%; paired $t(19)=1.58$ $p=.130$). His largely spared performance at regular inflection demonstrates that his weak overall performance may be almost entirely attributed to his particular problems with irregular past tenses. As previously reported, these were particularly problematic, likely due to impairments of the temporal-lobe based lexical/declarative memory system, with sparing of the grammatical/procedural system (Ullman et al., 1997; Ullman et al., in press).

JLU's pattern of past marking provides further support to our claim that the grammatical operations underlying inflection are spared in his case. Unlike the anterior aphasics, he produced past tense inflected forms in the majority (71%) of his errors: over-regularizations (*clinged, wringed*, and *maked*), over-irregularizations (*think-thank* cf. *sink-sank*), a multiply *–ed*-suffixed form (*stir-stirreded*), *–ed*-suffixed distortions (*strise-strivesed, drite-strited, scash-scatched, slub-slopped, trab-trapped, pob-probbed*) and a likely irregularization (*dig-dung*). His control subjects marked 70% of their errors for past tense, at virtually the same rate as JLU. Importantly, even once JLU's past-marked errors were combined with correctly inflected forms, his total rate of past-marking did not differ significantly from that of control subjects, on real verbs (94% vs. 99.7%; paired $t(35)=1.33$ $p=.191$) or novel ones (92% vs. 98%; paired $t(37)=1.55$ $p=.130$

Pattern of inflectional errors. JLU did not show the same pattern of errors as the anterior aphasics (Tables 1 and 2). Over all verbs, he produced only three unmarked forms (4% of items, 18% of errors). This rate did not differ significantly from his control subjects' rate of producing unmarked forms (4% vs. 1%, paired $t(73)=1.54$, $p = .130$, as a percentage of items). Furthermore, like the anterior aphasic control subjects (see above), most of the items for which he produced unmarked forms (2 out of 3) were novel verbs whose stems had a final /d/ and are phonologically appropriate regular past tense forms: *cleed*, and *preed*. Similarly, JLU's control subjects produced 6 unmarked forms total, all of which end in /d/ and are phonologically plausible regular past-tense forms (e.g., *preed*). Thus, the low rate of unmarked errors, as well as the type of items that they were produced on, is indicative of JLU's preserved capacity at computing the appropriate functional categories (and at *–ed*-affixation). Further strengthening this conclusion is the fact that unlike the anterior aphasics, but like the control subjects, JLU produced no *–ing*-, *–en*-, or *–s*- suffixed forms.

Five Posterior Aphasics with less Circumscribed Lesions

Performance at past tense inflection. Each patient was examined individually (Table 1). Four of the 5 patients – JMO, WBO, APE, and JHA - performed similarly to JLU. With all verb types combined, they were significantly more impaired than the control subjects at past-tense inflection (in paired t-tests over items, between control subjects' 96% and JMO: 80%, $t(73)=3.45$ $p=.001$; WBO: 88%, $t(73)=2.13$ $p=.037$; APE: 88%, $t(73)=2.07$ $p=.042$; JHA was unable to perform the task for novel verbs). A similar pattern was observed when the real and novel verbs were examined separately, although, in fact, in several analyses the posterior aphasics' score was *not* significantly lower than the control subjects'. On real verbs: control subjects 99% vs. 89% for JMO and APE, $t(35)=1.86 p=.071$; vs. 89% for WBO, $t(35)=1.93 p=.062$; vs. 75% for JHA, $t(35)=3.34$ $p=.002$. On novel verbs: control subjects 93% vs. JMO 71%, $t(37)=2.92$ $p=.006$; vs. WBO 87%, $t(37)=1.14$ $p=.263$; vs. APE 87%, $t(37)=1.11$ $p=.275$.

As in the case of JLU, the weak overall performance is attributable to the posterior aphasics' particular problems with lexical memory, and thus with irregular past tenses (Ullman et al., 1997; Ullman et al., in press). When the four aphasics' performance on real regulars alone was examined, none of them differed significantly from control subjects (control subjects' 99% vs. 90% for JMO, WBO, and APE, in each case $t(19)=1.347$ $p=.194$; vs. 85% for JHA, $t(19)=1.83$ $p=.083$). Similarly, on novel regulars, APE did not differ significantly from control subjects (85% vs. 94%, paired $t(19)=1.06$ $p=.303$); WBO was actually *better* than control subjects (100% vs. 94%, paired $t(19)=2.94$ $p=.008$) and only JMO was significantly worse than control subjects (50% vs. 94%, paired $t(19)=3.75$ $p=.001$).

Like JLU, but unlike the anterior aphasics, the four posterior aphasics had a high rate of past marking on incorrect responses. WBO inflected 56% of his errors for past tense, APE and JHA each inflected 67% of their errors for past tense, and JMO did so for 44% of his errors. Importantly, combining their past tense inflected errors and the correctly inflected forms yielded a rate of past tense marking that was not significantly different from that of control subjects, for real verbs (control subjects 99.7% vs. WBO 97%, $t(35)=0.87$ $p=.393$; vs. APE 94%, $t(35)=1.34$ $p=.191$; vs. 92% for JHA and JMO, $t(35)=1.70$ $p=.098$) or for novel verbs (control subjects 98% vs. WBO 92%, $t(37)=1.33$ $p=.193$; vs. APE 97%, $t(37)=0.23$ $p=.822$; vs. JMO 87%, $t(37)=1.93$ $p=.061$).

HFL was the only posterior aphasic who did not perform as we expected. Rather his performance corresponded to the predictions of the Hierarchy Complexity Hypothesis for anterior aphasics. He was significantly worse than control subjects over all verbs (46% vs. 96%, $t(73)=10.09$ $p<.0001$), over real verbs (56% vs. 99%, $t(35)=5.13$ $p<.0001$) and over novel verbs (37% vs. 94%, $t(37)=5.90$ $p<.0001$). However, unlike the other posterior aphasics, this poor overall performance cannot be attributed solely to his problems with irregular verbs. HFL was worse than control subjects at past-tense inflection for regular verbs (70% vs. 99%, $t(19)=2.76$ $p=.012$) and novel regulars (45% vs. 94%, $t(19)=4.48$ $p=.0003$). He was the worst of the 5 posterior aphasics at producing regulars; in fact, his performance on real regulars was significantly lower than that of all the other posterior aphasics ($t(15)=3.00$, $p=.009$ compared to JLU; $t(15)=2.42$, $p=.029$ compared to

JHA and JMO; $t(15)=3.42$, $p=.004$ compared to WBO and APE). Moreover, HFL marked only 18% of his incorrect responses for past tense. His rate of past marking (i.e., correct past-tenses combined with past-marked incorrect responses) was significantly lower than that of control subjects, for real verbs (64% vs. 99.7%; $t(35)=4.38$ $p=.0001$), for novel ones (47% vs. 98%; $t(37)=6.35$ $p<.0001$), and over all verbs (55% vs. 99%; $t(73)= 7.57$ $p<.0001$). Moreover, HFL was the only posterior aphasic to produce a large number of unmarked forms: a total of 27 (36% of responses, 68% of his errors), which is a similar response rate to that of the anterior aphasics. HFL's rate of unmarked forms was significantly higher than that of control subjects (36% vs. 1%; $t(73)=6.39$ $p<.0001$) and the other posterior aphasics ($t(73)=5.59$, $p<.0001$ compared to JLU; $t(73)=5.06$, $p<.0001$ compared to JMO; $t(73)=5.76$, $p<.0001$ compared to WBO; $t(73)=6.10$, $p<.0001$ compared to APE; $t(35)=3.25$, $p=.003$ compared to JHA). Similar to the anterior aphasics, but unlike the control subjects and other posterior aphasics, only one of his unmarked forms on real verbs, and only 5 of his unmarked forms on novel verbs ended in an alveolar stop /t/ or /d/. It is striking that HFL was the only posterior aphasic whose scan indicated damage to the caudate nucleus. His performance is consistent with the prediction of the Declarative/Procedural Model that the left basal ganglia subserve grammatical rule processing, and structure building in particular (Ullman, 2001a; Ullman, 2001b; Ullman et al., 1997). Moreover, his data suggest that the left caudate nucleus may play a particularly important role in this function. Indeed, this is supported by other studies, of both regular morphology (Ullman et al., 1997) and syntax (Moro et al., 2001). Finally, because HFL had fluent speech, these results also dissociate fluency from the structure-building grammatical function hypothesized to depend upon frontal/basal-ganglia structures.

<u>Pattern of inflectional errors.</u> Like JLU, the 4 posterior aphasics also had a very low rate of unmarked forms: 4% in the case of JMO, and 3% for WBO, APE, and JHA (results for JHA are calculated over real verbs only). None of these rates was statistically significantly different from the control subjects' 1% unmarked forms (in paired t-tests over items, JMO: $t(73) = 1.27$ $p=.210$; WBO: $t(73) = 0.90$ $p=.373$; APE: $t(73) = 0.84$ $p=.402$; JHA: $t(35)=0.87$ $p=.393$). Like the control subjects (see above), many of their unmarked forms were phonologically appropriate regular past-tense

forms. These constituted half of the errors made by WBO, APE, and JHA (*prend*, *blide, stand*). Finally, like the control subjects, these posterior aphasics did not produce any *–ing*-, *-en*-, or *–s*-suffixed forms.

Anterior Aphasia vs. Posterior Aphasia

We directly compared the performance of the anterior and posterior aphasics with circumscribed lesions: FCL and JLU. FCL was more impaired than JLU at the past tense production task: for all verbs (28% vs. 77%; paired t(73) = 5.92, p < .0001 over items), for real verbs (42%, vs. 78%; paired *t*(35)=2.845 *p*=.007), and for novel verbs (16% vs. 76%; paired *t*(37)=5.845 *p* < .0001). Despite JLU's significantly worse performance at irregulars than regulars, and FCL's worse performance at regulars than irregulars, the anterior and posterior aphasics did not differ significantly at their performance on irregular past tense inflection (69% vs. 63%; paired *t*(15)=.324 *p*=.751). FCL was also more impaired at marking past tense on errors and correct responses combined, for all verbs (35% vs. 93%; paired *t*(73)=8.37 *p*<.0001), for real verbs (44% vs. 94%; paired *t*(35)=5.35 *p*<.0001) and for novel verbs (26% vs. 92%; paired *t*(37)=6.47 *p*<.0001). FCL produced significantly more unmarked forms than JLU: for all verbs (24% vs. 4%; *t*(73)=3.73 *p* =.0004), for real verbs (22% vs. 3%, paired *t*(35)=2.907 *p*=.006) and for novel verbs (26% vs. 5% paired *t*(37)=2.458 *p*=.019). FCL also had a significantly higher production rate of participial forms (-*ing* and *–en*) than JLU (19% vs. 0%, *t*(73)=4.13, *p*<.0001). These direct comparisons between anterior and posterior aphasia further strengthen the Hierarchy Complexity Hypothesis.

Study 2: Past Tense Reading

Anterior Aphasia

The past tense reading task was successfully completed by 9 agrammatic anterior aphasics: FCL, CIG, WRO, LDO, PJ, KCL, NSL, HTA, and NWH. Of these, FCL completed the past tense production and judgment tasks as well. CIG and WRO were among the anterior aphasics who were tested on but could not complete the past tense production task. An additional anterior aphasic could not complete the past tense reading task.

Performance at past tense inflection. The anterior aphasics' performance revealed an impairment at inflection (Table 3). Their overall success rate at reading past-tense forms was significantly lower than that of the control subjects (40.8% vs. 99.6%; paired $t(33)=15.93$ $p<.0001$, over items; independent $t(15)=7.35$ $p<.0001$, over subjects). The significant difference also obtained when only irregular verbs were examined (51% vs. 99%, $t(16)=10.39$ $p<.0001$, over items; independent $t(15)=5.21$, $p < .0001$, over subjects), indicating an inflectional impairment beyond *–ed*-suffixation. The patients performed poorly on 10 irregular past-tenses that clearly involve no overt affixation (e.g., *clung, drove*) (44% vs. the subjects' 98%; paired $t(7)=10.14$, $p<.0001$, over items; independent $t(15)=5.24$, $p <.0001$, over subjects). Therefore, the anterior aphasics' deficit cannot be explained solely as an impairment at the level of affixation in morphophonology. A purely articulatory or phonological explanation is also unlikely, as the anterior aphasics were worse than control subjects at reading a subset of past-tense forms (see Methods) with no word-final complex consonant cluster, for regulars (e.g, *tried, showed*) (27% vs. the control subjects' 100%, paired $t(11)=15.15$ $p<.0001$, over items; independent $t(15)=7.01$, $p <.0001$, over subjects), for irregulars (e.g., *drove, bought*) (47% vs. the control subjects' 99%, paired $t(8)=7.46$ $p<.0001$, over items; independent $t(15)=5.44$, $p <.0001$, over subjects), and regulars and irregulars combined (35% vs. the control subjects' 99%, paired $t(20)=13.81$ $p<.0001$, over items; independent $t(15)=7.27$, $p <.0001$, over subjects).

In individual subject analyses, each of the 9 anterior aphasics was significantly impaired on overall inflection, compared to control subjects (in paired *t*-tests over items, between each of the 9 aphasics and control subjects, all *p*s < .0001). Similarly, all 9 aphasics showed worse performance than controls on irregular past-tenses (*p*s < .05 for 8 patients, $p =.4$ for one), non-t-affixed irregular verbs (ps < .05 for 6 patients; ps between .05 and .5 for three), and regular and irregular past-tenses with word-final simple codas (ps < .001 for 8 patients, p = .193 for one).

Pattern of inflectional errors. Over the two verb classes, the anterior aphasics' errors (Tables 3 and 4) consisted mostly of unmarked forms of the stimulus verb (22% of items, 36% of errors): 22% vs. 0.37% for control subjects; independent $t(15) = 5.63$ $p < .00005$, over subjects; paired $t(33)=6.86$ $p < .0000001$, over items. They also produced both *–ing* suffixed forms (3% of items, 6% of errors) and

–en-suffixed forms (1% of items, 1% of errors). The control subjects produced none. The aphasics' production rate of participial forms (*-ing* + *-en* forms) was significantly higher than that of the control subjects (4% vs. 0%, paired $t(33) = 3.783$, $p = .0006$). Their production rate of participial forms was significantly lower than that of their unmarked forms (4% vs. 22%, as a percentage of items: $t(33) = 5.43$, $p < .0001$, over items; $t(8) = 3.13$ $p = .014$, over subjects). (Anecdotally, HTA's response to reading *showed* revealed the expected pattern of errors; first he pointed to the *-ed* suffix and grimaced; after a pause, he said "show", pointed again the suffix and said "hard", and then spelled out "e-n," then said that response was wrong, and then spelled out "e-d.") The patients also produced a small number of *–s*-suffixations (1% of items, 1% of errors) while the control subjects produced none (independent $t(15)=1.42$ $p=.176$, over subjects; paired $t(33)=1.44$ $p=.160$, over items). The aphasics' rate of *–s*-suffixation was lower than their rate of producing participial forms (1% vs. 4%, as a percentage of items: $t(33) = 2.96$, $p = .006$, over items; $t(8)= 1.25$, $p = .247$, over subjects).

Individual subject analyses revealed similar patterns. Eight of the anterior aphasics produced unmarked forms at a greater rate than the control subjects (*p*s < .005 for 7 subjects, $p = .05$ for one). The one aphasic (CIG) who produced no unmarked forms instead produced many *–ing*-forms (24% of items vs. control subjects' 0%, $p=.006$) and one *–en*-form.

Four of the anterior aphasics (HTA, NWH, NSL, KCL) also read verb stems. As expected, these four aphasics performed significantly better at reading stems than reading past tense forms, over both verb types (69% vs. 49%; paired $t(33)= 3.477$ $p=.001$ over items; paired $t(3)= 5.714$ $p=.011$ over subjects) and over irregular verbs (71% vs. 53%; paired $t(16)= 2.219$ $p=.041$, over items; paired $t(3)=2.121$ $p=.124$ over subjects). This advantage at reading stem forms cannot be attributed to frequency differences, because for both the regular and irregular items the stems had slightly *lower* FK and AP frequencies than the past tense forms. The four anterior aphasics were also significantly better at reading stems than past tenses of verbs whose past-tense forms do not end in a consonant cluster (e.g., *speak-spoke, flow-flowed*), suggesting that the difficulty with past tense forms cannot be attributed to articulatory or perceptual factors (71% vs. 49%, paired $t(20)= 3.1$

p=.006, over items; paired *t*(3)= 3.45 *p*=.04, over subjects). Again, for these items the frequency of the stems was lower than that of their past tense forms (FK: 2.89 vs. 3.07; AP: 5.85 vs. 6.09). Finally, the four anterior aphasics performed better on stems than past tenses even on the subset of 8 non-*t*-affixed irregular verbs (78% vs. 47% paired *t*(7)= 5 *p*=.002, over items; paired *t*(3)= 3.87 *p*=.03 over subjects). Again, the stems of these verbs have lower frequencies than their past tenses (FK: mean 3.08 vs. 3.29; AP: mean 5.43 vs. 5.88). Moreover, the stem/past-tense reading pattern is unlikely to be attributed to orthographic differences, because both the past tenses and the stems have largely consistent spelling-to-sound correspondences (e.g., *cling-clung, hold-held*). Importantly, these past tense forms are exactly matched to their stems in terms of phonological complexity and acoustic saliency (e.g., *drive-drove, hold-held*), precluding an articulatory or perceptual explanation of the stem/past performance differences. As expected by the Hierarchy Complexity Hypothesis, the four anterior aphasics did not produce any -*ing*-suffixed, -*en*-suffixed or -*s*-suffixed forms in the stem reading task. The same aphasics produced 2 -*ing*-forms (*drove-driving*; *prayed-praying*), one -*en*-suffixed form (*hid-hidden*), one -*s*-suffixed form (*fled-flees*) and one -*s*-suffixed substitution (*kept-keps*) when reading the past tense forms. These findings support our hypothesis that such affixation errors are the result of the computation of functional projections.

[Table 3 about here]

[Table 4 about here]

<u>Posterior Aphasia</u>

Five posterior aphasics performed the past tense reading task (Tables 3 and 4). However, two of them (LBR and RHH) had poor performance on the stem reading task, indicating general reading impairments. The other three aphasics (YHY, HFL, and APE) were therefore analyzed separately. These three aphasics showed a pattern similar to that of the posterior aphasics in the past tense production task. They were somewhat more impaired than control subjects at computing the two past tense types combined (controls 99.6% vs. APE 91%, *p*=.098, over items; HFL 76%, *p*=.003; YHY 88%, *p*=.044), but did not show this impairment in reading regular past tenses (controls 100% vs. APE 94%, *p*=.332; HFL 82%, *p*=.083; YHY 94%, *p*=.332). (Unsurprisingly, HFL, who was impaired at regulars in the past tense production task, had the worst performance of the three aphasics on regulars in the reading task, although even his production rate was not significantly worse than that of the control subjects.) This demonstrates that their impairment at irregular verbs did not extend to inflection more generally. The three posterior aphasics produced few unmarked forms and no –*ing*-, -*en*-, or -*s*-suffixed forms. Two of the three produced unmarked forms, but at a rate not statistically significantly greater than that of the control subjects (YHY: 6%, p=.191; HFL: 3%, p=.393) nor different from zero (YHY: p=.160; HFL: p = .163, one-tailed), as measured by paired t-tests. Of the three posterior aphasics, only YHY was given the stem reading task as well. She performed worse on the past tenses than on the stems over both verb types (88% vs. 100%; paired $t(33)$=2.1, p=.044). However, on regular verbs alone her performance on past tenses and their stems did not differ significantly (94% vs. 100%; p=.332), suggesting that her problems with the past tenses was not due to problems with inflection but to lexical problems leading to difficulties with irregulars. Intriguingly, the two posterior aphasics who had poor performance on the stem reading task (LBR and RHH) performed significantly worse than control subjects not only over both past tense types, but also on regular past tenses alone(ps < .0001). Moreover, LBR produced many –*ing*-suffixed forms, although he produced no unmarked forms.

Study 3: Past Tense Judgment

Anterior Aphasia

Three agrammatic anterior aphasics performed the past tense judgment task (FCL, RBA, BMC). Two of them could not perform the task for novel verbs (RBA, BMC). One of them (BMC), who was unable to perform the past tense production or reading tasks, was able to rate half the items on the judgment task before he became too fatigued to continue. We analyzed these rated items, which constituted 15 irregular and 8 regular past tense forms, and 10 unmarked forms of regular verbs. The two subjects who were unable to rate novel verbs gave lower ratings than the control subjects to correct real regular and irregular past tense forms, with one of the differences being statistically significant (control subjects 95 out of 100 vs. BMC 29: $t(22)$=7.06 p<.0001, over items; vs. RBA 92: $t(35)$=0.647 p=.522). These two aphasics also gave lower ratings than control subjects to correct irregular past tense forms alone, again with one of the differences being statistically significant (control subjects 94 vs. BMC 37: $t(14)=4.60$ $p=.0004$, over items; vs. RBA 88: $t(15)=0.738$ $p=.472$). The third aphasic (FCL), who was able to perform the task for novel verbs, gave lower ratings than the control subjects to all correct past tense types combined (e.g., *dug, walked, plagged, crove, crived*; $t(91)=7.76$ $p<.0001$), as well as to correct real and novel irregulars separately (e.g., *dug, crove*; $t(33)=3.66$ $p=.001$).

All three anterior aphasics accepted unmarked forms in past tense contexts. All three rated unmarked forms significantly differently from zero (FCL: mean of 6, paired $t(39)=1.96$ $p=.029$, one-tailed; RBA: mean of 23, $t(19) = 2.49$, $p = .011$, one-tailed; BMC: mean of 60, paired $t(9)=4.13$ $p=.002$, one-tailed). Intriguingly, when FCL rejected the correctly inflected form *walked*, he motivated his judgment by saying "because … *walking*", suggesting that he computed the *–ing* form in this context.

Posterior Aphasia

JLU showed a very different pattern than the anterior aphasics. He gave the highest possible rating to all regular and irregular past tense forms. Similarly, he gave the highest rating to all novel regular past tense forms (e.g., *plagged*), and to 17 of the 18 regularizations of novel irregulars (e.g., *crived*). Moreover, unlike the anterior aphasics, he gave ratings of zero to all unmarked forms, for both real and novel regular verbs.

GENERAL DISCUSSION

In summary, all 11 anterior aphasics showed one or more aspects of the pattern predicted by the Hierarchy Complexity Hypothesis. In the two expressive language tasks (past tense production and reading), the anterior aphasics were impaired at past-tense inflection, not only failing to compute correct past tense forms, but failing to past-mark their errors as well. The 4 aphasics who were given a stem-reading task were significantly better at this task than at past tense reading. (A similar result has been reported by Badecker, (1997) who found that an anterior agrammatic had more trouble reading out loud isolated irregular and regular past-tense then stem forms (for discussion, see Ullman et al., in press).) The patients showed a graded pattern of errors, with a larger number of incorrect forms that are dependent upon lower than higher functional categories. Most errors were stem forms, there were fewer past and present participial forms, and the fewest –*s*-suffixed forms. This graded pattern was observed within individual patients. Between patients, there were differences in severity, with some patients having greater difficulty with past tense inflection and making more unmarked errors than others.

In contrast, the posterior aphasic with lesions circumscribed to temporal/temporo-parietal regions, and even most of those posterior aphasics with anterior extensions, did not show this pattern. They were not impaired at past-tense inflection, other than for irregular forms. They did not show the graded pattern of errors, producing few unmarked forms, and no past or present participles or –s-suffixed forms.

A similar anterior/posterior aphasia contrast was found in the judgment task. The anterior aphasics gave low ratings to past-tense inflected forms, and accepted stem forms in past-tense contexts. (Similarly, Hagiwara (1995) reported better agrammatic aphasic performance at judging linguistic forms that are dependent upon lower functional categories; see above.) The posterior aphasics gave normal ratings to past tense forms, and rejected stem forms in past-tense contexts. These results suggest that, even in receptive language, anterior but not posterior aphasics have difficulty computing past-tense inflection, and compute incorrect forms that are dependent upon lower projections.

The anterior aphasics' problem with past-tense inflection is revealed not only by the weak performance of those aphasics who completed the tasks, but also by the fact that a number of anterior aphasics that we tested were not able to perform the tasks at all. Five out of 7 anterior aphasics failed on the past tense production task, and one out of 10 anterior aphasics failed on the past tense reading task. Even in past tense judgment, one out of 3 anterior aphasics was not able to complete the task. In contrast all of the posterior aphasics were able to complete the past tense production, reading, and judgment tasks.

The impairment of past tense inflection in anterior aphasia cannot be entirely explained by difficulty with the morphological affixation impairment affecting regulars, as irregulars were impaired as well. Moreover, not only irregulars which are claimed to involve–*t*-affixation (Halle and Marantz, 1993), but also non-*t*-affixed irregulars were impaired. The inflectional impairment also cannot be entirely attributed to purely articulatory (Alexander, 1997) or phonological (Kean, 1980) deficits, because it is also found on past-tenses with simple codas, most of which, in the case of irregular verbs, are moreover not more complex than those of their stems.

Alternative explanations of the large number of unmarked forms produced or accepted in the three tasks also fail to account for all the data. First, the stems are provided to the aphasics in the past tense production and judgment tasks, and are thus the most readily available forms. However, the high number of unmarked forms in past tense reading cannot be accounted for in this manner, because that task involved no prior presentation of the stem. Second, the unmarked forms on regular verbs in the reading task could be explained by a tendency for the anterior aphasics to stop reading once a well-formed word is encountered. However, the numerous unmarked forms produced in reading irregular verbs (*bought-buy*) cannot be explained by this alternative explanation.

The above alternative explanations also face the problem of explaining the many –*ing*-form errors. Moreover, the much smaller number of -*s*-suffixations is important because it shows that –*ing* –forms are not simply the result of random affix-substitution. Although the dearth of –*s*-suffixed forms in the past tense production task may be attributable in part to agreement conflict with the first person subject in the presentation sentences (e.g., Yesterday I ….), such an explanation could not account for the low production rate of such forms in the isolated past tense reading task.

The data only partially conform to the predictions of Hagiwara (1995) and Friedmann & Grodzinsky (1997). According to both of these perspectives, the deficit is predicted to yield an all-or-nothing dichotomy, with equally and fully impaired functional projections above but not below a particular point in the hierarchy, at least within subjects. The data presented here demonstrate that this is not the case. The impairment is graded within individual subjects, who make more stem than participial and –s-suffixed errors. Moreover, the deficit in past-tense inflection, and the computation of stem forms in past-tense contexts, was found in a receptive task as well as the two expressive tasks. This does not appear to be consistent with the claim that the hierarchically-sensitive impairment exists only in expressive language.

These data are consistent with the Hierarchy Complexity Hypothesis, which predicts that both across and within anterior aphasics, for both expressive and receptive language tasks, linguistic forms dependent upon higher category projections are probabilistically less likely to be computed. (Note that we do not deny that other factors, such as differences between open- and closed-class words in articulatory difficulty, perceptual saliency and semantic content also contribute to agrammatism. Rather we argue that the patterns we have observed cannot be explained *solely* by these factors, and are best accounted for by the HCH.)

Previously reported data also appear to conform to the graded pattern predicted by the HCH. As we argued in the introduction, the findings discussed both by Hagiwara and by Friedmann and Grodzinsky appear to reflect a graded impairment rather than an all-or-nothing pattern. De Villiers (1974) reported an in-depth investigation of the spontaneous speech of 8 agrammatic aphasics. Within verbal inflection, she found that the aphasics (but not normal control subjects) produced –*ing*-forms more accurately than –*s*-forms or past tense forms. With nominals, the aphasics (but not control subjects) had much more trouble with articles and possessives than plurals — even though the articles are highly salient free function words, compared to the relatively less salient bound –*s*-suffixes among the plurals. This corresponds to the general view in syntactic theory that the highest projection for plurals is lower than that for possessives or articles (Ritter, 1995). Similarly, Goodglass and colleagues have reported that that –*s*-suffixed forms are more difficult for aphasics when used as 3rd person singulars or possessives than plurals, in both expressive and receptive tasks (Goodglass and Berko, 1960; Goodglass et al., 1972; Goodglass and Hunt, 1958). The pattern of possessive –*s*-being more affected than plural –*s* has also been found by Nadeau and Rothi (1992) based on the study of one Broca's aphasic's spontaneous speech. The same aphasic also had more problems with complementizers (dependent on C) than with auxiliaries (dependent on T). Support for the HCH also comes from languages other than English. Bleser and Bayer (1990) report the performance of one agrammatic aphasic in a reading test. This patient showed increasingly worse performance at higher functional categories: infinitives elicited the least number of morphological errors, followed by participles, followed by tensed present forms (with all forms being morphologically complex). Similarly, two Icelandic and one Hindi agrammatic aphasics were more impaired on tensed verbs than on infinitives and participles (Lorch, 1990).

A number of different deficits appear to be compatible with the Hierarchy Complexity Hypothesis. First, the data might be explained by a deficit affecting working memory. Hierarchical structures with higher projections are posited to have more elements that need to be combined. Thus greater working memory capacity is needed for linguistic forms dependent upon higher than (only) lower projections. Therefore a working memory deficit might lead to more trouble with forms dependent upon higher projections. Second, a deficit affecting movement could explain the results. A mechanism such as head-to-head movement is often posited in the derivation of inflected forms. This operation is posited to actually compose the stem and the affix (e.g., *walk+ing*) (Baker, 1985; Baker, 1988) or to “check” the abstract features of an inflected word that has already been composed in the lexicon (Chomsky, 1995). However, other mechanisms have also been proposed to create morphological forms, or check their features (Chomsky, 1999; Marantz, 1984). Moreover, movement is framework-specific, whereas some kind of combination of categories is adopted by all syntactic theories. There have also been neurolinguistic claims that head-movement is spared in agrammatic aphasia (Grodzinsky and Finkel, 1998). All these considerations undermine the likelihood that an operation of movement is responsible for the deficit of agrammatism.

A deficit affecting structure building, and in particular of combination (Merge), can account for the empirically observed agrammatic aphasic patterns predicted by the Hierarchy Complexity Hypothesis, both in the present study and in other data. This view is compatible not only with linguistic theory, but also with cognitive neuroscience theory.

According to the Declarative/Procedural model, the procedural brain system posited to be damaged in agrammatic anterior aphasia underlies structure building not only in syntax, but also in morphology. Therefore one should find concomitant syntactic and morphological structure building difficulties in the same patients. As discussed above, anterior aphasia is strongly linked to worse performance with regular than irregular forms. Indeed, as reported elsewhere, this pattern was found consistently among the patients in the present studies. Both patients given the production task showed the relative deficit of regulars, seven of nine showed it in the reading task, and all three showed it in the judgment task, as measured by percentage of correctly produced or read forms, acceptability ratings, or reaction times (Ullman et al., in press).

Moreover, it is unlikely that the co-occurrence of morphological and syntactic structure building impairments can be explained simply by serendipitous damage to nearby brain regions. Such damage should not lead to a correlation, over subjects, between the two types of impairments. A correlation is particularly unlikely to be caused by chance damage to nearby structures if the lesions are relatively circumscribed, as they were in many of the anterior aphasics examined in our studies.

However, we found that over all the anterior aphasics in the past tense production and reading tasks, the combined production rate of unmarked, participial, and –*s*-suffixed forms on *irregular* items correlated negatively with the percentage of successfully produced regular past tense forms: $r(9) = -0.52$, p = .098. Thus the worse the performance at computing regulars, the greater the hypothesized syntactic structure building deficit, as evidenced from the error pattern on the irregular items alone, independent of the regulars. This supports our hypothesis that morphological and syntactic grammatical computation, and in particular, morphological and syntactic structure building, are subserved by the same set of left anterior brain structures. Because this relation between the computation of regular forms and the observed errors on irregulars was predicted, it is justifiable to report p as one-tailed ($p = .049$); the statistically significant result further strengthens the conclusion. This same pattern was also observed for the smaller sample of the 9 anterior aphasics on the reading task alone: $r(7) = -0.55$, p = .060 one tailed. It could be argued that these correlations may be explained in part by the syntactic impairment's effect on computing regulars. However, the correlation was found even when another measure of syntactic structure building was held constant — that is, partialing out the combined production rate of unmarked, participial, and –*s*-

suffixed forms on *regular* items: $r(6) = -0.59$, $p = .062$ one tailed). In fact, the production of irregular participial and –*s*-suffixed forms alone predicted performance at regular forms, in the analogous partial correlation ($r(6) = -0.72$, $p = .020$ one tailed). These correlations thus demonstrate a link between morphological and syntactic structure building, and suggest that the two types of structure building depend on the same set of left anterior brain structures.

Several conclusions can be drawn from our findings. First, they provide independent evidence for a hierarchy of functional categories, and, moreover, for a particular ordering of those categories. Second, they suggest that the left anterior structures (including the caudate nucleus) damaged in anterior aphasia, but not the left posterior structures damaged in posterior aphasia, play a role in syntactic and morphological structure building, and in particular in combination (e.g., Merge). Third, the fact that the anterior aphasics' impairment at inflection was revealed in the isolated past tense reading task in addition to the production and judgment tasks has important implications for the processing of isolated inflected forms, and for theories of morphology. In particular, it suggests that reading inflected words not only involves morphological decomposition (Dell, 1986; Garrett, 1976; Taft, 1979), but also syntactic operations. Fourth, the fact that other populations of subjects may show similar patterns to those discussed here in agrammatic aphasia (Jakubowicz and Nash, 2001; Platzack, 2001) suggests that the Hierarchy Complexity Hypothesis may have explanatory power beyond this one language disorder.

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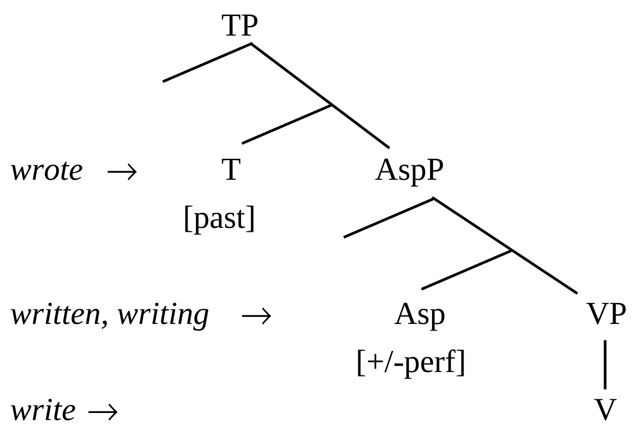

Figure. The structure behind verbal inflection in English

	FCL	***RBA***	***Controls to AA (12)***	***JLU***	***HFL***	***JHA***	***JMO***	***WBO***	***APE***	***HFL, JHA, JMO, WBO, APE***	***Controls to PA (8)***
Regular											
Correct	20 (4)	20 (4)	98 (236)	90 (18)	70 (14)	85 (17)	90 (18)	90 (18)	90 (18)	85 (85)	99 (159)
Past marked error	5 (1)	10 (2)	.4 (1)	5 (1)	0	5 (1)	0	5 (1)	0	2 (2)	.6 (1)
Ing-suffixed	40 (8)	10 (2)	0	0	0	0	0	0	0	0	0
En-suffixed	0	0	0	0	0	0	0	0	0	0	0
S-suffixed	0	0	0	0	0	0	0	0	0	0	0
Unmarked	30 (6)	40 (8)	1 (2)	5 (1)	30 (6)	0	5 (1)	0	5 (1)	8 (8)	0
Distortion	0	5 (1)	0	0	0	0	0	0	5 (1)	1 (1)	0
Word substitution	0	5 (1)	0	0	0	5 (1)	0	5 (1)	0	2 (2)	0
Ing-suffixed substitution	0	5 (1)	0	0	0	0	0	0	0	0	0
En-suffixed substitution	0	0	0	0	0	0	0	0	0	0	0
S-suffixed substitution	0	0	0	0	0	0	0	0	0	0	0
No response	5 (1)	5 (1)	.4 (1)	0	0	0	0	0	0	0	0
Other errors	0	0	0	0	0	5 (1)	5 (1)	0	0	2 (2)	0
Irregular											
Correct	69 (11)	25 (4)	96 (185)	63 (10)	38 (6)	63 (10)	88 (14)	88 (14)	88 (14)	73 (58)	98 (126)
Past marked error	0	19 (3)	3 (6)	25 (4)	6 (1)	25 (4)	6 (1)	13 (2)	13 (2)	13 (10)	.8 (1)
Ing-suffixed	13 (2)	0	0	0	0	0	0	0	0	0	0
En-suffixed	6 (1)	0	0	0	0	0	0	0	0	0	0
S-suffixed	0	0	0	0	0	0	0	0	0	0	0
Unmarked	13 (2)	44 (7)	.5 (1)	0	31 (5)	6 (1)	6 (1)	0	0	9 (7)	.8 (1)
Distortion	0	0	0	0	25 (4)	6 (1)	0	0	0	6 (5)	0
Word substitution	0	0	0	6 (1)	0	0	0	0	0	0	0
Ing-suffixed substitution	0	0	0	0	0	0	0	0	0	0	0
En-suffixed substitution	0	0	0	0	0	0	0	0	0	0	0
S-suffixed substitution	0	0	0	0	0	0	0	0	0	0	0
No response	0	0	0	0	0	0	0	0	0	0	0
Other errors	0	13 (2)	0	6 (1)	0	0	0	0	0	0	0
Novel Regular											
Correct	5 (1)	NA	95 (228)	80 (16)	45 (9)	NA	50 (10)	100 (20)	85 (17)	70 (56)	94 (150)
Past marked error	15 (3)	NA	4 (10)	20 (4)	5 (1)	NA	25 (5)	0	15 (3)	11 (9)	6 (9)
Ing-suffixed	15 (3)	NA	0	0	0	NA	0	0	0	0	0
En-suffixed	0	NA	0	0	0	NA	0	0	0	0	0
S-suffixed	0	NA	0	0	0	NA	0	0	0	0	0
Unmarked	35 (7)	NA	.4 (1)	0	30 (6)	NA	5 (1)	0	0	10 (7)	0
Distortion	0	NA	0	0	10 (2)	NA	0	0	0	3 (2)	0
Word substitution	0	NA	.4 (1)	0	0	NA	0	0	0	0	.6 (1)
Ing-suffixed substitution	0	NA	0	0	0	NA	0	0	0	0	0
En-suffixed substitution	0	NA	0	0	0	NA	0	0	0	0	0
S-suffixed substitution	0	NA	0	0	0	NA	0	0	0	0	0
No response	20 (4)	NA	0	0	0	NA	0	0	0	0	0
Other errors	10 (2)	NA	0	0	10 (2)	NA	20 (4)	0	0	9 (6)	0
Novel Irregular											
Correct	28 (5)	NA	91 (196)	72 (13)	28 (5)	NA	89 (16)	72 (13)	89 (16)	69 (50)	93 (134)
Past marked error	6 (1)	NA	4 (8)	11 (2)	17 (3)	NA	6 (1)	11 (2)	6 (1)	10 (7)	3 (5)
Ing-suffixed	0	NA	0	0	0	NA	0	0	0	0	0
En-suffixed	0	NA	0	0	0	NA	0	0	0	0	0
S-suffixed	0	NA	0	0	0	NA	0	0	0	0	0
Unmarked	17 (3)	NA	5 (10)	11 (2)	56 (10)	NA	0	11 (2)	6 (1)	18 (13)	3 (5)
Distortion	0	NA	0	0	0	NA	0	0	0	0	0
Word substitution	17 (3)	NA	.5 (1)	6 (1)	0	NA	0	0	0	0	0
Ing-suffixed substitution	0	NA	0	0	0	NA	0	0	0	0	0
En-suffixed substitution	0	NA	0	0	0	NA	0	0	0	0	0
S-suffixed substitution	0	NA	0	0	0	NA	0	0	0	0	0
No response	28 (5)	NA	0	0	0	NA	0	0	0	0	0
Other errors	6 (1)	NA	.5 (1)	0	0	NA	6 (1)	6 (1)	0	3 (2)	0

Table 1. Responses in Past Tense Production Task: Anterior and Posterior Aphasics

Note. Response rates as percentages of items (number of items in parentheses). The posterior aphasics' scores for novel verbs are calculated over 4 aphasics because one (JHA) could not perform the task for novel verbs.

	FCL	*RBA*	*FCL and RBA,*	*Control subjects to AA (12)*	*JLU*	*HFL, JHA, JMO, WBO, APE*	*Control subjects to PA (8)*
Inflectional error							
Unmarked	24 (18)	42 (15)	32 (23)	2 (14)	4 (3)	8 (15)	1 (6)
Participle	19 (14)	6 (2)	18 (13)	0	0	0	0
Ing-suffixed	18 (13)	6 (2)	17 (12)	0	0	0	0
En-suffixed	1 (1)	0	1 (1)	0	0	0	0
S-suffixed	0	0	0	0	0	0	0

Table 2
Morphosyntactic Errors on the Past Tense Production Task.

Note. Response rates as percentages of items (number of items in parentheses). RBA was unable to carry out the task for novel verbs; percentages for both RBA and for FCL and RBA combined are calculated over real verbs only. JHA could not perform the task for novel verbs; percentages for the total of 5 posterior aphasics are for real verbs only.

	FCL	*CIG*	*WRO*	*LDO*	*PJ*	*KCL*	*NSL*	*HTA*	*NWH*	*Mean AA (9)*	*LBR*	*YHY*	*RHH*	*HFL*	*APE*	*Mean PA (5)*	*Control Subjects (8)*
Regular																	
Correct	41 (7)	0	6 (1)	18 (3)	35 (6)	41 (7)	29 (5)	29 (5)	76 (13)	31 (47)	12 (2)	94 (16)	24 (4)	82 (14)	94 (16)	61 (52)	100 (136)
Past marked errors	12 (2)	12 (2)	0	6 (1)	18 (3)	0	12 (2)	6 (1)	0	7 (11)	6 (1)	0	18 (3)	0	6 (1)	6 (5)	0
Ing-suffixed	0	24 (4)	0	0	6 (1)	6 (1)	0	0	0	4 (6)	18 (3)	0	0	0	0	4 (3)	0
En-suffixed	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S-suffixed	0	0	0	6 (1)	0	0	0	0	0	.7 (1)	0	0	0	0	0	0	0
Unmarked	24 (4)	0	47 (8)	53 (9)	24 (4)	29 (5)	35 (6)	35 (6)	24 (4)	30 (46)	0	6 (1)	0	6 (1)	0	2 (2)	0
Distortion	6 (1)	0	0	0	0	0	0	0	0	.7 (1)	12 (2)	0	24 (4)	0	0	7 (6)	0
Word substitution	18 (3)	18 (3)	35 (6)	18 (3)	12 (2)	6 (1)	0	24 (4)	0	14 (22)	35 (6)	0	35 (6)	6 (1)	0	15 (13)	0
Ing-suffixed substitution	0	18 (3)	0	0	0	0	0	0	0	2 (3)	18 (3)	0	0	0	0	4 (3)	0
En-suffixed substitution	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S-suffixed substitution	0	0	6 (1)	0	0	0	0	0	0	.7 (1)	0	0	0	0	0	0	0
No response	0	29 (5)	6 (1)	0	6 (1)	0	0	6 (1)	0	5 (8)	0	0	0	0	0	0	0
Other errors	0	0	0	0	0	18 (3)	24 (4)	0	0	5 (7)	0	0	0	6 (1)	0	1 (1)	0
Irregular																	
Correct	56 (9)	24 (4)	35 (6)	65 (11)	71 (12)	71 (12)	24 (4)	24 (4)	94 (16)	51 (78)	24 (4)	82 (14)	12 (2)	71 (12)	88 (15)	55 (47)	99 (135)
Past marked error	6 (1)	0	6 (1)	6 (1)	6 (1)	0	0	0	6 (1)	3 (5)	12 (2)	0	12 (2)	6 (1)	6 (1)	7 (6)	0
Ing-suffixed	0	18 (3)	0	0	0	0	6 (1)	0	0	3 (4)	6 (1)	0	0	0	0	1 (1)	0
En-suffixed	0	6 (1)	0	0	0	0	0	6 (1)	0	1 (2)	0	0	0	0	0	0	0
S-suffixed	0	0	0	0	0	0	0	6 (1)	0	.7 (1)	0	0	0	0	0	0	0
Unmarked	19 (3)	0	12 (2)	18 (3)	18 (3)	12 (2)	24 (4)	18 (3)	0	13 (20)	0	6 (1)	0	0	0	1 (1)	.7 (1)
Distortion	0	0	0	0	0	6 (1)	6 (1)	0	0	1 (2)	35 (6)	12 (2)	47 (8)	12 (2)	6 (1)	22 (19)	0
Word substitution	12 (2)	12 (2)	41 (7)	12 (2)	6 (1)	0	18 (3)	24 (4)		14 (21)	18 (3)	0	29 (5)	6 (1)		11 (9)	0
Ing-suffixed substitution	0	18 (3)	0	0	0	0	0	0	0	2 (3)	0	0	0	0	0	0	0
En-suffixed substitution	6 (1)	0	0	0	0	0	0	0	0	.7 (1)	0	0	0	0	0	0	0
S-suffixed substitution	0	0	0	0	0	0	6 (1)	0	0	.7 (1)	0	0	0	0	0	0	0
No response	0	24 (4)	6 (1)	0	0	0	6 (1)	12 (2)	0	5 (8)	0	0	0	0	0	0	0
Other errors	0	0	0	0	0	12 (2)	12 (2)	12 (2)	0	4 (6)	6 (1)	0	0	6 (1)	0	2 (2)	0

Table 3.

Responses in Past Tense Reading Task: Anterior and Posterior Aphasics

Note. Response rates as percentages of items (number of items in parentheses). The percentages reported for FCL's performance on irregulars are based on 16 rather than 17 items because of a presentation error of one of the irregular items.

	Anterior (9)	*Posterior (5)*	*Control Subjects (8)*
Inflectional error			
Unmarked	22 (66)	2 (3)	.4 (1)
Participle	4 (12)	2 (4)	0
Ing-suffixed	3 (10)	2 (4)	0
En-suffixed	.7 (2)	0	0
S-suffixed	.7 (2)	0	0

Table 4

Morphosyntactic Errors on the Past Tense Reading Task.

Note. Response rates as percentages of items (number of items in parentheses).