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Neural Correlates of Lexicon and Grammar: Evidence from the Production, Reading, and Judgment of Inflection in Aphasia

Running Page Heading:

Lexicon and grammar in aphasia

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ABSTRACT

Are the linguistic forms memorized in the mental lexicon and those specified by the rules of mental grammar subserved by distinct computational and neuroanatomical systems or by a single computational system with relatively broad anatomic distribution? On a dual-system view, the productive *–ed*-suffixation of English regular past tense forms (e.g., *look-looked*) depends upon the mental grammar, whereas irregular forms (e.g., *dig-dug*) are retrieved from lexical memory. On a single-system view, the computation of both past tense types depends on associative memory. Neurological double dissociations between regulars and irregulars strengthen the dual-system view. The computation of real and novel, regular and irregular past tense forms was investigated in twenty aphasic subjects. Aphasics with non-fluent agrammatic speech and left frontal lesions were consistently more impaired at the production, reading, and judgment of regular than irregular past tenses. Aphasics with fluent speech and word-finding difficulties, and with left temporal/temporo-parietal lesions, showed the opposite pattern. The findings support the view that the memorized words of the mental lexicon are subserved by a brain system involving temporal/temporo-parietal structures, whereas aspects of the mental grammar, in particular the computation of regular morphological forms, are subserved by a distinct system involving left frontal structures (see Ullman et al. (1997). *Journal of Cognitive Neuroscience*, *9*(2), 266-276).

INTRODUCTION

In the study of language, a fundamental distinction is drawn between the "mental lexicon" and the "mental grammar." The lexicon contains memorized pairings of sound and meaning. It must contain at least those words whose phonological form and meanings cannot be derived from each other, such as the non-compositional word *cat*. It may also contain other non-compositional forms, smaller or larger than words: bound morphemes (e.g., the *–ed* past tense suffix, and the root *nomin* in *nominal* and *nominate*) and idiomatic phrases (e.g., *kick the bucket*). The grammar contains rules, including operations and constraints, which underlie the sequential and hierarchical combination of lexical forms into predictably structured larger words, phrases, and sentences. That is, the grammar subserves the computation of compositional linguistic forms whose meaning is transparently derivable from their structure. For example, a mental rule which specifies that English past tense forms are derived from the concatenation of a verb stem and an *-ed* suffix would allow us to compute past tenses from new words (e.g., *fax* + *-ed* → *faxed*) and from novel forms (e.g., *blick* + *-ed* → *blicked*). Rule-derived forms can thus be computed in real-time, and so do not need to be memorized — although even compositional linguistic forms (e.g., *walked*) could in principle be memorized in the lexicon (Berko, 1958; Chomsky, 1965; Chomsky, 1995; de Saussure, 1959; Pinker, 1994).[1]

These two language capacities have been explained by two competing theoretical frameworks. "Dual-system" theories posit distinct cognitive and neural components for the two capacities (Chomsky, 1965; Chomsky, 1995; Damasio & Damasio, 1992; Fodor, 1983; Pinker, 1994). On this view, the learning, representation, and/or processing of words in a rote or associative memory is subserved by one or more components, which may be specialized and dedicated ("domain-specific") to these functions (Bloom, 1994; Chomsky, 1965; Chomsky, 1995; Fodor, 1983; Forster, 1979; Levelt, 1989; Levelt, 1992; Markman & Hutchinson, 1984; Pinker, 1994; Seidenberg, 1985; Swinney, 1982; Waxman & Markow, 1996). The use of stored words may be especially dependent upon left posterior regions, particularly temporal and temporo-parietal structures (temporo-parietal referring to the supramarginal and angular gyri) (Damasio & Damasio, 1992; Damasio, Grabowski, Tranel, Hichwa, & Damasio, 1996; Dejerine, 1901; Geschwind, 1965; Goodglass, 1993; Lichtheim, 1885; Luria, 1966; Wernicke, 1874). The learning, knowledge, and/or processing of grammar are subserved by one or more components that are specialized and dedicated to their linguistic functions, and which have been posited to be innately-specified (Chomsky, 1965; Chomsky, 1995; Fodor, 1983; Frazier, 1987; Pinker, 1994). The use of grammar has been claimed to be dependent on left frontal cortex, particularly Broca's area (the inferior left frontal gyrus, which contains the cytoarchitectonic Brodmann's areas 44 and 45 (Damasio, 1992)) and adjacent anterior regions (Bradley, Garrett, & Zurif, 1980; Caramazza, Berndt, Basili, & Koller, 1981; Damasio & Damasio, 1992; Grodzinsky, 2000; Zurif, 1995), although this is controversial, in particular regarding the comprehension of syntax (e.g., Hickok, 2000).

In contrast, "single-system" theories posit that the learning and use of the words and rules of language depend upon a single system that has a relatively broad left hemisphere anatomic distribution, and which is general-purpose ("domain-general") in that it also subserves non-language functions (Bates & MacWhinney, 1989; Elman et al., 1996; MacDonald, Pearlmutter, & Seidenberg, 1994; MacWhinney & Bates, 1989; Rumelhart & McClelland, 1986; Seidenberg, 1997). On this view, there is no categorical distinction between non-compositional and compositional forms. Rather, rules are only descriptive entities, and the language mechanism gradually learns the entire statistical structure of language, from the arbitrary mappings in non-compositional forms to the rule-like mappings of compositional forms. Modern connectionism has offered a computational framework for the single system view. It has been argued that the learning, representation, and processing of grammatical rules as well as lexical items takes place over a large number of inter-connected simple processing units. Learning occurs by adjusting weights on connections on the basis of statistical contingencies in the environment (Elman et al., 1996; Rumelhart & McClelland, 1986; Seidenberg, 1997).

Single and double dissociations which differentially link the lexicon to left posterior regions and aspects of grammar to left anterior regions suggest that these regions contain distinct neural underpinnings which play different roles in the knowledge or processing of the two capacities, as predicted by a dual system view. Such dissociations have been revealed by several experimental approaches.

Aphasia. There are at least two fundamental types of aphasia. These constitute an empirically-demonstrated categorical distinction with respect to several behavioral and neuroanatomical dimensions. The dichotomy has variously been described as receptive/expressive, fluent/non-fluent, and posterior/anterior. Each label focuses on a different dimension of the aphasic impairment, such as whether it primarily affects input or output, how it affects speech production, and whether its associated lesions are in the anterior or posterior portions of the left hemisphere (Alexander, 1997; Caplan, 1987; Caplan, 1992; Dronkers, Pinker, & Damasio, in press; Goodglass, 1993; Goodglass, Quadfasel, & Timberlake, 1964). Fluent aphasia involves speech that is facile in articulation and relatively normal in phrase length. It is associated with "anomia"— impairments in the production and reading of "content" words, such as nouns and verbs — and with deficits in the recognition of content word sounds and meanings. Fluent aphasics' lexical difficulties can be contrasted with their tendency to not omit either morphological affixes (e.g., the past tense *-ed* suffix) or "function" words, such as articles and auxiliaries, in their speech and reading. They also generally produce sentences whose syntactic structures are relatively intact. Fluent aphasia is strongly associated with damage to left temporal and temporo-parietal regions. Non-fluent aphasia involves speech that is effortful, with a reduction of phrase length and grammatical complexity. This "agrammatic speech" in non-fluent aphasia is strongly associated with impairments at producing morphological affixes (e.g. *-ed*) and function words. They also often have difficulties using syntactic structure to understand sentences, and may have deficits at judging the grammaticality of sentences involving particular types of structures. In contrast, non-fluent aphasics are relatively spared in their use of content words. Non-fluent aphasia is associated with damage to left frontal structures (Caplan, 1992; Caramazza et al., 1981; Dronkers et al., in press; Goodglass, 1993; Goodglass & Wingfield, 1997; Grodzinsky, 2000; Grodzinsky & Finkel, 1998).

Electrophysiology. Event-related potential (ERP) studies support the dissociations noted in aphasia. The "N400" is a central/posterior negative component which is associated with manipulations of word sounds and meanings (Hagoort & Kutas, 1995; Kutas & Hillyard, 1980; Kutas & Hillyard, 1983), and has been linked to left temporal lobe structures (Nobre, Allison, & McCarthy, 1994; Papanicolaou, Simos, & Basile, 1998). In contrast, a left anterior negativity ("LAN") has been associated with grammatical violations (Hagoort & Kutas, 1995; Kutas & Hillyard, 1983; Neville, Nicol, Barss, Forster, & Garrett, 1991; Osterhout, McLaughlin, & Bersick, 1997).

Neuroimaging. Positron Emission Tomography (PET) and functional Magnetic Resonance Imaging (fMRI) have also revealed dissociations between lexicon and grammar. Posterior activation in left temporal and/or temporo-parietal regions has been associated with semantic categorical judgements of auditorily presented word pairs (Wise, Chollet, Hadar, Friston, & Hoffner, 1991), with naming colors, faces, animals, and tools (Damasio et al., 1996; Martin, Haxby, Lalonde, Wiggs, & Ungerleider, 1995; Martin, Wiggs, Ungeleider, & Haxby, 1996), and with same/different judgments on sentence pairs containing identical syntax, but differing in one word (Bookheimer, Zeffiro, Gaillaird, & Theodore, 1993). In contrast, left anterior activation has been found in Broca's area when subjects gave acceptability judgments to syntactically more complex sentences, as compared to syntactically less complex sentences (Caplan, Alpert, & Waters, 1998; Stromswold, Caplan, Alpert, & Rauch, 1996), or same/different judgments to sentences differing in word order, but having the same meaning and containing identical words (Bookheimer et al., 1993).

However, there is also evidence, reviewed immediately below, suggesting that posterior regions may play a role in certain grammatical abilities, and that frontal areas play a role in certain lexical abilities.

Aphasia. Fluent aphasics can have "paragrammatic" speech, characterized by the incorrect use of morphological affixes, particularly by the frequent substitutions of one affix for another. Fluent aphasics have also been shown to have trouble using syntactic structure to understand sentences in standard off-line measures, and can be impaired in judging their grammaticality (although on-line measures designed to capture real-time language processing suggest that fluent aphasics have normal syntactic reflexes). Non-fluent aphasics usually have trouble retrieving content words in free speech (although they are relatively spared at recognizing such words). Moreover, they may retain the ability to make grammaticality judgments about certain syntactically complex sentences (Alexander, 1997; Caplan, 1987; Caplan, 1992; Dronkers et al., in press; Goodglass, 1993; Grodzinsky & Finkel, 1998; Linebarger, Schwartz, & Saffran, 1983; Love, Nicol, Swinney, Hickok, & Zurif, 1998; Swinney, Zurif, Prather, & Love, 1996).

Electrophysiology. A posterior positive ERP component, usually maximal over parietal areas and bilaterally symmetric (the "P600"), is associated with syntactic violations (Hagoort & Kutas, 1995; Osterhout et al., 1997). (Note however, that the sources of neither the LAN nor the P600 have been anatomically localized.)

Neuroimaging. Posterior activation has been found when subjects listen to sentences as compared to word lists (e.g., Mazoyer et al., 1993). Increasing the syntactic complexity of visually presented sentences has been found to yield increased bilateral frontal and temporal activation (Just, Carpenter, Keller, Eddy, & Thulborn, 1996). Anterior activation is associated with the search, selection, or retrieval of word sounds and meanings (Buckner & Peterson, 1996; Frith, Friston, Liddle, & Frackowiak, 1991; Martin et al., 1996).

The lack of clear and consistent neuroanatomical dissociations between lexicon and grammar has kept the dual-system/single-system controversy very much alive. Testing for lexicon/grammar dissociations has been problematic because tasks probing for lexicon and for grammar usually differ in ways other than their use of the two capacities. For example, it is difficult to match measures of grammatical processing in sentence comprehension with measures of lexical memory (see Bates, Harris, Marchman, Wulfeck, & Kritchevsky, 1995). A more productive approach to investigate the brain bases of lexicon and grammar may be to examine simple language phenomena that are well-studied from linguistic, psycholinguistic, developmental, and computational perspectives.

Regular and Irregular Morphology

We have therefore investigated the dual-system/single-system controversy by examining relatively simple language phenomena in which the use of lexical memory and grammatical rules can be contrasted while other factors are held constant, and which have been well-studied from linguistic, psycholinguistic, developmental, and computational perspectives. These phenomena are drawn from the domain of morphology, which concerns the structure of words. Formal linguistic theory, psycholinguistic theory, and empirical investigations have focussed extensively on whether morphologically complex words are computed on-line by the application of rules or are stored in memory as analyzed or unanalyzed wholes. Much of this research has examined this memory/rule distinction with respect to inflectional and derivational morphology. Inflectional morphology involves the transformation of words to fit their roles in phrases and sentences (e.g., verb conjugations and noun declensions). Derivational morphology involves the creation of new lexical forms out of old ones. Competing theories have posited that only derivational, both derivational and inflectional, or neither type of morphologically complex forms are stored in the mental lexicon (Aronoff, 1976; Chomsky, 1970; Garrett, 1980; Garrett, 1982; Kiparsky, 1982; Mohanan, 1986; Selkirk, 1982; Stanners, Neiser, Hernon, & Hall, 1979; Stemberger & MacWhinney, 1986; Stemberger & MacWhinney, 1988). Although these two types of morphology can be dissociated (Badecker & Caramazza, 1989; Coslett, 1986; Garrett, 1980; Garrett, 1982; Laudanna, Badecker, & Caramazza, 1992; Miceli & Carmazza, 1988), they also share many similarities (Halle, 1973; Halle & Marantz, 1993; Lieber, 1992; Sciullo & Williams, 1987; Stanners et al., 1979; Stemberger & MacWhinney, 1986; Stemberger & MacWhinney, 1988).

In particular, both inflectional and derivational morphology contain a range of types of morphophonological transformations, from those that are highly productive, and serve as the default (e.g., English past tense *–ed*-suffixation and nominalizing *–ness*-suffixation, as in *walk-walked* and *eager-eagerness*), to those that are relatively or completely unproductive (e.g., in *go-went, break-broke, take-took; solemn-solemnity*). Here we use the term "regular" to refer to the former class of transformations, and "irregular" to refer to (at least) the latter class. Crucially, regulars and irregulars are intrinsically matched in complexity (one word), meaning (e.g., past), and syntax (e.g., tensed), and can also be matched on syllable structure (e.g., *slept/slipped*), word frequency, and other factors (see Pinker, 1991; Pinker, 1994; Spencer, 1991).

The regular/irregular distinction in English past tense has been intensively investigated in recent years. English past tense transformations range from the fully productive *–ed*-suffixation, which applies as a default to new words and to novel forms (e.g., *fax-faxed*, *blick-blicked*), to the completely unproductive suppletive transformations (e.g., *go-went*). Crucially, there are also a variety of partially productive transformations in between (e.g., *sing-sang*, *spring-sprang*, *ring-rang*; cf., *fling-flung*, *bring-brought*). One might view these intermediate forms, which we also refer to as irregulars, as constituting the crux of the English past tense single-system/dual-system debate.

According to a traditional view, (at least) suppletive irregular past-tenses such as *went* are stored in and retrieved from a rote memory list of items, whereas regular forms (e.g., *looked*, *played*, *patted*) are computed in real-time by mental *–ed*-suffixation rules (Bybee & Moder, 1983; Bybee & Slobin, 1982; Halle & Marantz, 1993; Halle & Mohanan, 1985; Hoard & Sloat, 1973; Vennemann, 1971). It has variously been posited that the partially productive irregulars (e.g., *sang*, *rang*) are real-time products of "stem-readjustment" rules (Halle & Marantz, 1993; Halle & Mohanan, 1985; Hoard & Sloat, 1973), or are simply stored in rote memory (Bybee & Moder, 1983; Bybee & Slobin, 1982; Vennemann, 1971).

An alternative theory, which supports the single system view, posits that regulars and irregulars are learned in and computed over an associative memory which can be modeled by a single connectionist network. Here there is no categorical distinction between regulars and irregulars. There is no set of rules and no distinct system to process rules. Morphological rules, as well as other rules in language, are only descriptive entities. The language mechanism gradually learns the entire statistical structure of morphology (and the rest of language), from exceptional mappings (e.g., *go-went, teach-taught*), to rare mappings (*spring-sprang, sing-sang, ring-rang*), to the rule-like mappings of regular forms. In support of this theory, a number of connectionist (i.e., artificial neural network) models have been developed in which input and output units represent the sounds of verb stems and past tense forms, respectively, and in which the weights of a matrix of input-output connections are adjusted according to how the statistical structure of stem-past pairs influences the behavior of the network (Cottrell & Plunkett, 1991; Daugherty & Seidenberg, 1992; Hare & Elman, 1995; Hare, Elman, & Daugherty, 1995; MacWhinney & Leinbach, 1991;

Marchman, 1993; Plunkett & Marchman, 1991; Plunkett & Marchman, 1993; Rumelhart & McClelland, 1986; Seidenberg & Daugherty, 1992).

A third perspective, which we will argue for here, is that the computation of all English irregular past-tense transformations, from suppletives to those which are partially predictable, involves their retrieval from an associative lexical memory, whereas a distinct rule-processing system underlies the real-time computation of regulars (Marcus, Brinkmann, Clahsen, Wiese, & Pinker, 1995; Marcus et al., 1992; Pinker, 1991; Pinker & Prince, 1988; Pinker & Prince, 1991; Prasada & Pinker, 1993; Ullman, 1993; Ullman, 1999a; Ullman et al., 1997b). On this view, the learning, representation, and computation of irregulars depend on an associative memory which may be modeled by the sort of connectionist systems described above, and in particular by those whose recurrent connections among units allow for the settling of activity into stable attractor patterns (e.g. Plaut, McClelland, Seidenberg, & Patterson, 1996). In contrast, it is assumed that regulars are computed in real-time by a distinct symbol-manipulating system (Newell & Simon, 1981) which concatenates word bases (e.g., *walk, rat, happy*) with suffixes (e.g., *-ed, -s, -ness*) (Chomsky, 1965; Marcus et al., 1995; Pinker, 1991; Ullman et al., 1997b). The computation of an inflectional or derivational form involves the parallel activation of the two systems, one of which attempts to compute a form in associative memory, while the other attempts to compute a rule-product (Pinker & Prince, 1991). As the memory-based computation proceeds (e.g., during settling into an attractor pattern), a continuous signal is sent to the rule-processing system, indicating the probability of the successful computation (retrieval) of a memorized form. It is this signal which inhibits the “regular rule” (Pinker & Prince, 1991). Thus the computation of *dug* inhibits (“blocks”) the computation of *digged*. When an irregular is not successfully retrieved, the rule may be applied, resulting in “over-regularization” errors such as *digged* (Marcus et al., 1992; Pinker, 1991; Pinker & Prince, 1991; Ullman, 1993; Ullman et al., 1997b)[2].

English past tense represents a case in which fully productive affixal default (“regular”) transformations contrast with largely unproductive non-default (“irregular”) transformations that involve stem-changes. There are other categories of morphological transformations, including those that are affixal but relatively unproductive (e.g., German participle *–en* suffixation (Marcus et al., 1995) and Japanese adjectival past-tense *–katta* suffixation (Fujiwara & Ullman, 1999)), and those that are both affixal and highly productive but not a default (e.g., Bulgarian plural suffixation, in which the *–ove* suffix applies productively to monosyllabic masculine words, including new words and novel forms, but in which the default appears to be the *–i* suffix). Whether each of these types of transformation are rule-based or are computed in associative memory is an empirical question. However, we hypothesize that any *individual* inflected or derivational form, including forms which could in principle be computed by mental rules (e.g., the form *walked*), *can* be stored in associative memory. Indeed, psycholinguistic and neurolinguistic evidence suggests that certain types of regular past tense forms are indeed likely to be memorized (Ullman, 1993; Ullman, in press).

Linguistic, psycholinguistic, and developmental studies of inflectional and derivational morphology have presented evidence in support of a dual-system view. Distinct components have been implicated in the use of (largely) unproductive non-default versus productive default inflection by investigations of English past tense and plural inflection (Gordon, 1985; Kim, Pinker, Prince, & Prasada, 1991; Kiparsky, 1982; Pinker, 1991; Prasada & Pinker, 1993; Prasada, Pinker, & Snyder, 1990; Stanners et al., 1979; Ullman, 1993; Ullman, 1999a; Ullman & Izvorski, 1999), German participle and plural inflection (Clahsen, 1999; Marcus et al., 1995; Sonnenstuhl, Eisenbeiss, & Clahsen, In Press), and Japanese adjectival inflection (Fujiwara & Ullman, 1999). For example, psycholinguistic studies have shown that for irregular (*dig-dug*) but not regular (*walk-walked*) verbs, generation times and acceptability judgments of past tense forms are predicted by their frequencies, even when holding stem frequencies or stem acceptability ratings constant (Prasada et al., 1990; Ullman, 1993; Ullman, 1999a). Similar results have been obtained in children (van der Lely & Ullman, submitted). These findings have been interpreted as indicating that irregular but not regular past tense forms are retrieved from memory. Similarly, the computation of English irregular but not regular past tenses is sensitive to the number of "neighboring" verbs with similar-sounding stem-past mappings (Ullman, 1993; Ullman, 1999a). These contrasting "neighborhood effects" have also been obtained for novel verbs, between "novel irregulars," whose computation is sensitive to neighboring real irregulars, (e.g., *spling-splang*; c.f. *spring-sprang, sing-sang*), and "novel regulars," which do not show analogous neighborhood effects with respect to real regular verbs (e.g., *plag-plagged*) (Prasada & Pinker, 1993). The similarity-based computation and partial-productivity of irregular but not regular inflection suggests that irregulars but not regulars depend upon associative memory. A similar distinction has been found in Japanese adjectival past tense inflection, between the largely unproductive non-default *–katta*-suffixation, which is sensitive to phonological neighborhood effects, and the productive default *–datta*-suffixation, which is not (Fujiwara & Ullman, 1999). Developmental studies have revealed that the less often a child hears an irregular past tense form, the more likely s/he is to produce its over-regularized form (Marcus et al., 1992; van der Lely & Ullman, submitted). This has been taken to suggest that the less frequently an irregular past tense form is encountered, the weaker will be its memory traces, and the lower will be the probability that it will be retrieved and that the application of an *–ed*-suffixation rule will be blocked (Marcus et al., 1992; Pinker, 1991). Linguistic and psycholinguistic investigations also suggest distinct components for regular and irregular derivational morphology (Aronoff, 1976; Bradley, 1979; Kiparsky, 1982; Siegel, 1979; Stanners et al., 1979). For example, in a lexical decision task, the recognition reaction times of irregular but not regular derivational forms (e.g., *solemnity* vs. *awkwardness*) were predicted by the frequencies of those forms. This was taken to suggest that irregular but not regular derivational forms are memorized (Bradley, 1979).

However, it has been argued that many empirically observed linguistic, psycholinguistic, and developmental distinctions between regular and irregular morphology can be simulated by connectionist networks, which may thus provide a full account of irregular and regular morphology (Cottrell & Plunkett, 1991; Daugherty & Seidenberg, 1992; Hare & Elman, 1995; Hare et al., 1995; MacWhinney & Leinbach, 1991; Marchman, 1993; Plunkett & Marchman, 1991; Plunkett & Marchman, 1993; Rumelhart & McClelland, 1986; Seidenberg, 1992; Seidenberg & Daugherty, 1992). For example, a lack of frequency effects among regulars might be explained by the generalization of stem-past patterns common to many regular verbs, which could overwhelm individual word memory traces (Seidenberg, 1992; Seidenberg & Daugherty, 1992). Likewise, the negative correlations between irregular past tense frequency and over-regularization rates (Marcus et al., 1992) may be explained by the fact that weak mappings of lower frequency irregulars (*blow-blew*) might not be able to compete successfully against strong stem-past mappings of the many regulars with similar-sounding stems (*flowed, showed, rowed*) (Plunkett & Marchman, 1991; Plunkett & Marchman, 1993).

Connectionist models can even yield double dissociations (Plaut, 1995) — although, as we discuss below, *not* the double dissociations between regulars and irregulars that are predicted by dual-system theories. In the domain of reading aloud, connectionist models have posited orthographic, phonological, and semantic representations, each subserved by distinct sets of units (Plaut et al., 1996; Plaut & Shallice, 1993; Seidenberg & McClelland, 1989). Each set of units, and the pathways between them, may also be "neuroanatomically distinct" (Plaut, In Press). Although the models assume distinct representations and pathways, they crucially also assume a uniformity of processing mechanisms. All representations and pathways underlie the reading of all words, whether they be regular (i.e., with a pronunciation that obeys a set of spelling-sound correspondence rules, e.g. *mint*) or irregular (e.g. *pint*). Indeed, the models do not acknowledge a categorical distinction between regular and irregular words. Rather, the key variable is a word's *consistency* — a continuous variable which "expresses the degree to which the pronunciation of a word agrees with those of similarly spelled words" (Plaut, In Press). The greater the consistency of a word, the easier it is for the "phonological pathway" (orthography to phonology) to learn its mappings. Words with low consistency might not be well-learned by the phonological pathway, and may thus be particularly dependent upon the "semantic pathway" (orthography to semantics to phonology). Indeed, upon training a network in the context of support from semantics, and then removing that support, Plaut et al. (1996) found that the network made more errors at inconsistent than consistent words. Thus in this model a lesion can yield worse performance at computing irregulars than regulars — not because the two types of words are subserved by distinct systems, but because irregulars depend more than regulars on the lesioned pathway.

Importantly, there appear to be no reported simulations of this model of reading aloud showing the *opposite* pattern, that of regulars being more impaired than irregulars (Friedman, 1998; Plaut, 1998). Indeed, to our knowledge, such a pattern has not been found in simulations of oral reading, nor is it empirically observed in patients, who tend to be at least as good at reading regulars as irregulars, holding constant factors such as frequency and word length (Friedman, 1998; Plaut, 1998). Rather a *different* double dissociation is empirically commonly found in oral reading: between non-words and irregular words (Coltheart, Curtis, Atkins, & Haller, 1993; Friedman, 1998; Plaut, 1998). It is this pattern which is predicted by these connectionist models of oral reading: Damage to phonological representations or the phonological pathway is expected to lead *not* to more errors with regulars than irregulars, but to a greater impairment in processing non-words than regular and irregular words (i.e., phonological dyslexia) (Coltheart et al., 1993; Friedman, 1998; Plaut, 1998; Plaut et al., 1996). Thus the oral reading domain appears to be fundamentally different from the dual-system predictions of the morphology domain: Double dissociations between regular and irregular forms are predicted by dual-system theories in morphology, but are not found in oral reading, nor are they predicted by connectionist models of oral reading.

Neural Dissociations between Regulars and Irregulars

The demonstration of double dissociations between regular and irregular morphological forms would strengthen the dual-system view, and would pose a challenge to single-system models. The dual-system view would be particularly strengthened by evidence linking irregulars to lexical memory and to specific brain regions (i.e., posterior structures), and regulars to aspects of grammar and to brain regions (i.e., frontal structures) distinct from those involved in irregulars . Such a pattern would suggest the existence of distinct components, with one being more important for irregulars (lexicon) than for regulars (grammar), and tied to posterior structures, and the other being more important for regulars than irregulars, and tied to frontal structures. Here we examine several reports of regular/irregular dissociations which have been presented as supporting a dual system model.

Aphasia. Several studies have reported that non-fluent aphasics (with left anterior damage) are worse at producing (Ullman et al., 1997b; Ullman et al., 1994) and reading (Badecker & Caramazza, 1987; Badecker & Caramazza, 1991; Marin, Saffran, & Schwartz, 1976; Ullman et al., 1997b; Ullman, Hickok, & Pinker, 1995) regular than irregular English past tense forms. Moreover, fluent aphasics (with left posterior damage) have been found to show the opposite pattern in past tense production (Ullman et al., 1997b; Ullman et al., 1994). This double dissociation suggests that regular and irregular past tense computation, particularly in production, depend on distinct neural underpinnings. It also links regulars to left anterior structures, and irregulars to left posterior regions.

The existence of distinct neural underpinnings is further strengthened by double dissociations in a cross-modal priming study (Marslen-Wilson & Tyler, 1997). One aphasic subject showed priming between past tense and stem forms for regulars (e.g., *jumped* primed *jump*), but not for irregulars (e.g., *gave* did not prime *give*). Two other aphasic subjects showed positive priming effects for irregulars and an interference effect (slowing) for regulars. Unfortunately, all three aphasics had very large lesions, precluding localization of the impaired functions. In the case of the first aphasic the damage involved parts of the left frontal, parietal, and temporal lobes, as well as inferior parietal and temporal structures in the right hemisphere. One of the other aphasics had a large left hemisphere lesion affecting the middle and posterior parts of the frontal lobe and most of the temporal lobe. A PET scan of the third aphasic showed no active metabolism in the left hemisphere.

Neurodegenerative disease. Neurological studies of adults with degenerative brain disease have revealed double dissociations between the production of irregularly and regularly inflected forms, and have linked irregulars to the lexicon and to temporal lobe regions and regulars to grammar and to frontal/basal-ganglia structures (Ullman, in press; Ullman et al., 1997b; Ullman et al., 1994; Ullman et al., 1993).

Alzheimer's disease (AD) is associated with the degeneration of temporal and temporo-parietal regions, and the relative sparing of the basal ganglia and frontal cortical regions, particularly Broca's area (e.g., Arnold, Hyman, Flory, Damasio, & Hoesen, 1991). The temporal and temporo-parietal damage may explain AD impairments at retrieving and recognizing words (Grossman et al., 1998; Nebes, 1989). In contrast, the majority of studies suggest that AD patients are relatively unimpaired at syntactic processing — in spontaneous speech (Appell, Kertesz, & Fisman, 1982; Bayles, 1982; Hier, Hagenlocker, & Shindler, 1985; Kempler, Curtiss, & Jackson, 1987; Murdoch, Chenery, Wilks, & Boyle, 1987; Nicholas, Obler, Albert, & Helm-Estabrooks, 1985; Price et al., 1993), elicited sentence production (Schwartz, Marin, & Saffran, 1979), sentence comprehension (Rochon, Waters, & Caplan, 1994; Schwartz et al., 1979; Waters, Caplan, & Rochon, 1995), and identification or correction of errors (Cushman & Caine, 1987; Whitaker, 1976); similar contrasts have also been shown in French (Irigaray, 1973; see Obler, 1981). See Nebes (1989) for a review. It has been shown that AD patients with severe deficits at object naming make more errors producing irregular than regular English past tense forms. Moreover, their error rates at object naming correlate with their error rates at producing irregular but not regular or *–ed*-suffixed novel past tenses (Ullman, in press; Ullman et al., 1997b; Ullman et al., 1994; Ullman et al., 1993). Similarly, Cappa and Ullman (1998) reported that Italian AD patients had more difficulty producing irregular than regular present tense and past participle forms in Italian.

Parkinson's disease (PD) is associated with the degeneration of dopaminergic neurons in the basal ganglia, causing high levels of inhibition in the motor and other frontal cortical areas to which the basal ganglia circuits project. This is thought to explain why PD patients show the suppression of motor activity (hypokinesia) and have difficulty expressing motor sequences (Dubois, Boller, Pillon, & Agid, 1991; Willingham, 1998; Young & Penney, 1993). PD patients may also have difficulty with grammar, both in comprehension (Grossman et al., 1993a; Grossman et al., 1991; Grossman, Carvell, Stern, Gollomp, & Hurtig, 1992; Lieberman, Friedman, & Feldman, 1990; Lieberman et al., 1992; Natsopoulos et al., 1991) and production (Grossman, Carvell, & Peltzer, 1993b; Illes, Metter, Hanson, & Iritani, 1988). In contrast, temporal-lobe regions remain relatively undamaged and the recognition of words remains relatively intact, in low- or non-demented PD patients (Dubois et al., 1991). In investigations of the PD production of regular and irregular past tense forms, it was found that severely hypokinetic PD patients showed a pattern opposite to that found among the AD patients, making more errors producing regular and *–ed*-suffixed novel forms than irregular forms. Moreover, across PD patients, the level of right-side hypokinesia, which reflects left basal ganglia degeneration, correlated with error rates at the production of regular and *–ed*-suffixed novel forms but not irregular forms. Intriguingly, left-side hypokinesia, which reflects right basal ganglia degeneration, did not show the analogous correlations with error rates in the production of any past tense type, underscoring the role of left frontal/basal-ganglia structures in grammatical rule use (Ullman, in press; Ullman et al., 1997b; Ullman et al., 1994; Ullman et al., 1993).

The double dissociation between AD and PD patients has been taken to suggest that temporal lobe regions are more important in the use of irregulars (and the lexicon more generally) than regulars (and grammar more generally); and that left frontal/basal-ganglia structures are more important in the use of regulars (and grammar) than irregulars (and lexicon) (Ullman, in press; Ullman et al., 1997b). However, the anatomical conclusions from AD must be treated with caution. Because brain pathology was not ascertained among the particular English- or Italian-speaking AD patients in these studies, their lexical deficits may be attributed to damage in regions other than temporal or temporo-parietal structures.

<u>Electrophysiology</u>. Two ERP studies of German inflection and one of Italian inflection have recently been reported (Gross, Say, Kleingers, Munte, & Clahsen, 1998; Penke et al., 1997; Weyerts, Penke, Dohrn, Clahsen, & Münte, 1996). In all three studies, default ("regular") and unproductive non-default ("irregular") items yielded distinct difference waves for incorrectly versus correctly inflected forms. These results were taken to suggest that affixation-based and lexically-based inflection are subserved by distinct brain structures (Clahsen, 1999).

However, this conclusion is problematic in certain respects (see Ullman, 1999b). In two of the studies, of German and Italian past-participle inflection, only the irregulars yielded large difference waves. The absence of substantial difference waves for regulars is consistent not only with dual-system models, but also with single-system models that posit that regulars and irregulars are computed by the same neural processes, but that incorrect irregulars are particularly difficult to process. Much stronger support for a dual-mechanism view would come from double dissociations that link regulars and irregulars to distinct difference waves. It is also puzzling why different ERP patterns were found in each of the three studies. Whereas the German plural and past participle incorrect irregulars yielded left anterior negativities (compared to correct irregulars), Italian incorrect irregulars yielded widespread but somewhat right lateralized negativities. And whereas the incorrect regulars yielded a central negativity for German plurals, this was not found for the other two studies.

The most convincing results were found in the German plural study. Incorrect irregulars yielded a left anterior negativity (LAN). In contrast, incorrect regulars produced an N400. As in the other two ERP studies, the incorrect regulars were irregularized (*–n*-suffixed) forms, and the incorrect irregulars were regularized (*–s*-suffixed) forms. Clahsen (1999) suggests that the LAN reflects grammatical processes of affixation, whereas the N400 may be tied to lexical processing. However, the violations of regulars and irregulars confound lexical and grammatical processes. The presentation of an over-regularization such as *mouses* involves a violation of the lexical expectancy of *mice* as well as an application of the suffixation rule, making it impossible to link the LAN to either lexical or grammatical processing. Similarly, irregularizations of regulars involve both a grammatical violation — a failure of the rule to apply — and the formation of an irregular-like novel, again making an unambiguous interpretation of the observed N400 impossible. Thus, this ERP study is important in that it suggests a neurophysiological dissociation between the processing of regulars and irregulars, but it stops short of linking either regular or irregular transformations to electrophysiological patterns that are independently associated with grammatical or lexical-semantic processing.

In contrast, in a recent ERP study of regular and irregular English past tense morphology, incorrect regulars and irregulars were presented as stem forms (e.g., Yesterday I *walk* after lunch). In comparisons to ERP waves of correctly inflected forms, incorrect regulars (i.e., an illicit absence of past-tense affixation) yielded a LAN, whereas incorrect irregulars (i.e., an illicit absence of a memorized past-tense form) yielded a more central distribution (Newman, Neville, & Ullman, 1998). In a second study designed to directly compare regular/irregular morphology and syntax/lexical-semantics, subjects viewed sentences with and without violations of syntactic phrase structure and lexical-semantics (after Neville et al., 1991), as well as the violations of regular and irregular past-tense morphology described above. Violations of regular verb inflection and syntactic phrase structure yielded LANs, whereas the waveform yielded by the incorrect irregulars and the N400 yielded by the lexical-semantic anomalies were more posterior (Newman, Izvorski, Davis, Neville, & Ullman, 1999). Crucially, these results tie regular morphology to syntax. They also dissociate regular morphology and syntax from irregular morphology and lexical-semantic processing.

<u>Neuroimaging</u>. Jaeger et al. (1996) reported a PET study of English past tense. Healthy English-speaking men were asked to read out loud lists of irregular, regular, and novel verb stems, and to produce their past tense forms. In the comparison between brain activation levels of past tense production and verb stem reading, left temporal and temporo-parietal regions were associated with greater statistical significance for irregular than regular or novel verbs, whereas a left prefrontal region was associated with greater statistical significance for regular and novel verbs. Unfortunately, this contrast is problematic in several respects. First, the pattern was not found when past tense production conditions were compared to a rest condition. Second, activation differences found from the comparison of two conditions can result from an increase in one condition or a decrease in the other, compared to a reference condition; in the absence of examination of activation decreases, these cannot be distinguished. Third, the blocking of large numbers of items required by PET might allow subjects to use a strategy to produce the regulars, all of which undergo -*ed*-suffixation, but not the irregulars, each of which requires a unique stem-past transformation. For additional comments on this study, see Seidenberg and Hoeffner (1998)

In a PET study of German verbal inflection, healthy German-speaking subjects were asked to produce past tense and past participle forms of regular and irregular German verbs (Indefrey et al., 1997). Sentences requiring past tenses and those requiring past participles were randomized within scans to avoid response strategies. Between scans, verbs were varied with respect to regularity. In direct comparisons of the regular and irregular conditions, ten cortical areas yielded more signal for irregulars than for regulars, including left and right frontal regions, and left temporal cortex. Two cortical areas showed more signal for regulars than for irregulars: right inferior temporal gyrus and left angular gyrus. Thus different patterns were observed in the irregular and regular verb conditions. The authors concluded that the "stronger cortical activation for irregular verbs and little overlap in activation for regular and irregular verbs are easier to reconcile with dual process models." Their finding that activation increases in the left dorsolateral prefrontal cortex is more strongly associated with irregular inflection than with regular inflection appears to be at variance with the claims of the dual system model. However, German irregular past participle formation, unlike English irregular past tense formation, involves morphological affixation (in addition to any stem changes), and since affixation may involve a grammatical operation, irregulars may be expected to activate areas subserving grammar in addition to those subserving memory (see discussion above). In addition, there was no report of activation decreases, compared to a reference condition. As described above, in the absence of an examination of activation decreases, a difference between two task conditions could be attributed to either an increase in one condition, or a decrease in the other.

English past tense has also been investigated with fMRI. Five healthy adults were shown the stems of irregular (e.g., *sleep*) and regular (e.g., *slip*) verbs on a screen, and were asked to silently ("covertly") produce their past tense forms (Bergida, O'Craven, Savoy, &

Ullman, 1998; Ullman, Bergida, & O'Craven, 1997a). Twenty seconds of regulars (10 verbs) were followed by 20 seconds of fixation (looking at a cross on the screen), 20 seconds of irregulars (10 verbs), and 20 seconds of fixation. This sequence was repeated for a total of 80 irregular and 80 regular verbs. The 5 subjects showed similar patterns of activation. In left frontal cortex, irregulars yielded a greater activation increase than regulars, whereas regulars yielded a greater decrease, compared to the fixation condition. The opposite pattern was found in left and right temporal lobe regions, where regulars yielded a greater increase than irregulars, while irregulars yielded a greater decrease, compared to fixation. Although the specific causes of these activation changes remain to be investigated, the contrasting patterns of activation suggest that irregulars and regulars have distinct neural underpinnings linked to temporal and frontal regions. However, the blocking (albeit with few items) of regular and irregular verbs suggests caution in interpreting the results.

Magnetoencephalography (MEG). This technique provides a method to investigate the real-time spatio-temporal dynamics associated with the production of regular and irregular past tense forms. Rhee, Pinker, and Ullman (1999) recorded from a whole-head 64-channel magnetometer while subjects produced past tenses of regular and irregular verbs. Satisfactory solutions to the inverse problem of dipole fitting for data averaged over all subjects were found at a number of 10 millisecond time-slices following stimulus presentation. No right-hemisphere dipoles were found. Dipoles in both the regular and irregular verb conditions were localized to a single left temporal/parietal region (250 to 310 milliseconds). Dipoles in left frontal regions were found only for regular verbs, and only for time-slices immediately following the left temporal/parietal dipoles (310-330 milliseconds). The results are consistent with a dual-system model in which temporal/parietal-based memory is searched for an irregular form, whose successful retrieval blocks the application of a frontal-based suffixation rule (Ullman et al., 1997b).

In sum, the regular/irregular distinction within inflectional morphology provides an excellent model for distinguishing between dual-system and single-system theories. Results from previous studies suggest cognitive and neural dissociations between regulars and irregulars. However, there has been limited evidence which indicates double dissociations between regulars and irregulars and that also links the two types of inflectional forms to their posited underlying linguistic capacities and to particular brain regions — namely, which indicates links among regulars, grammar, and left frontal cortex, and among irregulars, lexicon, and temporal or temporo-parietal cortex. It is therefore important to further test for these double dissociations and their neuroanatomical and functional bases.

Three Studies

Here we report in-depth investigations of the computation of regular and irregular inflection by non-fluent aphasics (with agrammatic speech and left frontal lesions) and fluent aphasics (with word-finding difficulties and left temporal/temporo-parietal lesions). We investigated these agrammatic non-fluent and anomic fluent aphasics' production, reading, and judgment of past tenses of regular and irregular English verbs (e.g., *drop-dropped*, *sleep-slept*) as well as their production and judgment of "novel regular" and "novel irregular" verbs (e.g., *spuff-spuffed*, *cleep-clept*). These investigations encompass new data as well as additional analyses of data reported by Ullman et al. (1997b). We also provide a detailed discussion of previously reported studies of regular and irregular morphology in aphasic patients.

If it is the case that the computation of real and novel regular past tenses (e.g., *looked*, *plagged*), and of over-regularizations (*digged*), rely on grammatical computations subserved by left frontal cortex, and that real irregular past tense forms are retrieved from a lexical memory largely dependent upon left temporal/temporo-parietal structures, then we should expect that non-fluent aphasics (with agrammatic speech and left frontal damage) will have more trouble with regulars and other *–ed*-suffixed forms than with irregulars, whereas fluent aphasics (with anomia and left temporal/temporo-parietal damage) will show the reverse pattern. If the computation of novel irregularizations (e.g., *crive-crove*) depends upon memory traces that underlie phonologically similar real irregular forms (e.g., *drive-drove*) (Bybee & Moder, 1983; Prasada & Pinker, 1993), these should pattern with irregulars.

Study 1: Regular and irregular past tense production. We predicted that agrammatic non-fluent aphasics should have more trouble producing regular than irregular past tense forms, for both real verbs (e.g., *slip-slipped* vs. *sleep-slept*) and novel verbs (e.g., *brip-bripped* vs. *cleep-clept*). Moreover, even when these patients fail to produce the correct irregular form, they should not over-regularize (*sleeped*). We also predicted that anomic fluent aphasics should show the opposite pattern[3]. That is, they should have more trouble producing irregular than regular past tenses, of both real and novel verbs. Such patients, given their impairment of lexical memory and hypothesized relative sparing of grammar, would be likely to produce over-regularizations.

Study 2: Regular and irregular past tense reading. Our predictions for the production of regular and irregular verbs by the two patient groups may also extend to the reading out loud of isolated past-tense forms. The predicted dissociations should be found if reading isolated inflected words involves their morphological parsing, as would be expected if such forms are comprehended (e.g., Coltheart, Patterson, & Marshall, 1980; Patterson, Marshall, & Coltheart, 1985), or simply if reading out loud requires mechanisms that also underlie the production of past tense forms. If reading regular (but not irregular) past tense forms depends upon the invocation of an *-ed*-suffixation rule, then agrammatic non-fluent aphasics may be worse at reading the past tense forms of regular than irregular verbs. If reading irregular past tense forms involves accessing associative memory for stored past tense forms as well as the parsed verb stem, whereas reading regular past tenses generally involves accessing only the parsed stem in memory, then anomic fluent aphasics may show the opposite pattern.

Study 3: Regular and irregular past tense judgment. If non-fluent and fluent aphasia are associated with the impairment of the knowledge and/or processing of grammatical rules and stored lexical forms, respectively, in (at least certain) receptive as well as expressive contexts, then we might also find double dissociations between regular and irregular past tense judgment. We therefore expected that agrammatic non-fluent aphasics would have more trouble computing real and novel *–ed*-suffixed forms (e.g., *walked, plagged, crived*), than real and novel irregular forms (e.g., *dug, crove*), and that they should therefore give lower acceptability ratings to the former than the latter past tense types. In contrast, anomic fluent aphasics should show the opposite pattern.

To sum up, we made the following predictions: (1) Agrammatic non-fluent aphasics are expected to have greater difficulty producing, reading, and judging regular and other *–ed*-suffixed past tenses than irregular past tenses. (2) Anomic fluent aphasics are expected to show the opposite pattern.

SUBJECTS

Eleven non-fluent aphasics, 9 fluent aphasics, and 64 unimpaired control subjects were given and were able to perform one or more of three tasks: past tense production, past tense reading, and past tense judgment. All subjects were native speakers of American or Canadian English. All aphasic subjects suffered a left hemisphere stroke (cerebral vascular accident) or, in one case, a resected aneurysm. None of the aphasic subjects had any known right-hemisphere damage. All aphasic subjects were right-handed before their lesion onset. Global aphasics, diagnosed on the basis of the Boston Diagnostic Aphasia Exam (BDAE; Goodglass and Kaplan (1983)) or the Western Aphasia Battery (WAB; Kertesz (1982)), were not included in the study. Aphasic subjects were classified as either non-fluent or fluent aphasic on the basis of clinical and behavioral data. Aphasic subjects were categorized as non-fluent aphasics if they had non-fluent speech. All non-fluent 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 non-fluent aphasics were diagnosed as Broca's aphasics, on the basis of the BDAE or WAB; the remaining non-fluent aphasic did not receive a clinical classification. Aphasic subjects were categorized as fluent if they had fluent speech. All fluent aphasics had word-finding difficulties (anomia). Lesion data were available for seven fluent aphasics, all of whom suffered damage to left temporal or temporo-parietal structures, with little or no frontal involvement. The remaining two fluent 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; Goodglass, 1993; Naeser & Hayward, 1978). Three of the 9 fluent aphasics were diagnosed as anomic aphasics, 3 as Wernicke's aphasics, and 3 did not receive a clinical classification. The non-fluent and fluent aphasics' demographic data are shown in Table 1. Clinical and behavioral summaries are shown in Table 2. A summary of lesion data is presented in Table 17. Additional behavioral data, together with detailed lesion reports where available, are presented in the Appendix.

[Table 1 about here]

[Table 2 about here]

Unimpaired Control Subjects

Sixteen cognitively unimpaired subjects were tested on the past tense production task as controls for the aphasic patients. These control subjects were split into two groups (with 4 subjects participating in both groups) to match the non-fluent and fluent aphasic groups in age and education. Twelve right-handed native English speakers served as controls for the non-fluent aphasics. Eight were female, and four were male. They had a mean age of 64 years and a mean of 15 years of education; the two non-fluent aphasic patients able to complete the past tense production task (FCL and RBA) were tested at 59 and 65 years of age, respectively, and both had 16 years of education. Eight right-handed native English speakers served as controls for the fluent aphasics. Seven were female, and one was male. There was no significant difference between the fluent aphasics and their controls in age (mean of 56 vs. 48 years, $t(11) = 1.44$, $p = .178$) or education (mean of 14 vs. 15 years, $t(11) = 0.35$, $p = .731$).

Eight unimpaired right-handed native English speakers (4 females and 4 males) were given the past tense reading task. These subjects served as controls for both the fluent and the non-fluent aphasics. The mean age of the non-fluent aphasics was 60 years, of the fluent aphasics was 58, and of controls was 59. Both the non-fluent and fluent aphasics had a mean of 15 years of education, and the controls had a mean of 17 years of education. There were no statistically significant differences in age or years of education between the control subjects and either the fluent aphasics (age: independent measures $t(11) = .098$, $p = .924$; education: $t(11) = 1.528$, $p = .155$) or the non-fluent aphasics (age: independent $t(15) = .194$, $p = .848$; education: $t(15) = 1.879$, $p = .080$)

Forty undergraduates at MIT were given the past tense judgment task. They served as control subjects for both the fluent and non-fluent aphasics. Although they were younger than the aphasic subjects, their presumed level of education (12 to 16 years) was similar to that of that of the four aphasic subjects (12, 14, 16, and 16 years).

STUDY 1: PAST TENSE PRODUCTION

Method

Materials

Subjects were presented with 80 verbs. (1) 20 "consistent"*regular* verbs (*look-looked*). Their stems are phonologically similar to the stems of other regular verbs, and dissimilar to the stems of irregular verbs, and thus they and their phonological neighbors are "consistently" regularized (e.g., *balk-balked*, *stalk-stalked*). None of their stems rhyme with the stems of irregulars; nor do they have /t/ or /d/ as a final consonant, because many irregular stems end in one of these two phonemes (e.g., *wet*, *bite*, *ride*, *bend*). (2) 20 *irregular* verbs, each with a single irregular past tense (e.g., *dig-dug*); "doublet" verbs, which take both an irregular and a regular past tense form, such as *dive-dove/dived*, were not included among these verbs. (3) 20 *novel regular* verbs, made-up verb stems which are phonologically similar to the stems of one or more regular verbs, but are not phonologically similar to the stems of any existing irregulars. Their expected pasts are therefore regular (*plag-plagged*). (4) 20 *novel irregular* verbs, made-up verb stems which are phonologically similar to the stems of existing irregulars, and whose possible past tense forms might therefore be irregularized or regularized (e.g., *crive-crove/crived*, c.f. *drive-drove, jive-jived*).

[Table 3 about here]

[Table 4 about here]

Three irregular verbs (*hit, split, slit*) and two novel irregular verbs (*ret, scrit*) were excluded from all analyses because their actual or likely past tense forms are identical to their stems, and therefore the production of past tense and stem forms cannot be distinguished. An additional irregular verb (*grind*) was excluded from analysis because its past tense form (*ground*) exists as a distinct verb. These exclusions were made before data analysis. Thus a total of 20 regular, 16 irregular, 20 novel regular, and 18 novel irregular verbs were tested and analysed in the past tense production task. Subjects were also presented with 20 doublet verbs (*dive-dove/dived*), for which both regular and irregular past tenses are acceptable, and 20 *inconsistent regular* verbs, whose stems are phonologically similar to the stem of one or more irregular verbs (e.g., *glide-glided*, c.f. *hide-hid, ride-rode*), and thus they and their neighbors do not follow a consistent stem-past mapping. We have argued elsewhere (Ullman, 1993) that doublet regular forms (*dived*) are likely to be memorized; if they were not, their corresponding irregulars (*dove*) could block them, under a dual-system view. Similarly inconsistent regular past tense forms are also likely to be memorized; otherwise people might utter non-existent forms like *glid* or *glode,* which moreover could block computation of the regular form *glided*. Inconsistent regulars are not discussed in this paper. Doublet regulars are discussed only under the past tense judgment task.

Tables 3 and 4 show the real and novel, regular and irregular verbs, together with the real verbs' relative frequencies, drawn from two sources: (1) Frequency counts derived by Francis and Kucera (1982) from 1 million words of text drawn from several sources selected to cover a range of topics. (2) Frequency counts extracted from a 44 million word corpus of unedited Associated Press news wires from February through December of 1988, by a stochastic part-of-speech analyzer (Church, 1988). Hereafter the two frequency counts are respectively referred to as "FK" and "AP." Both counts distinguished different parts of speech — e.g., *talked* used as a past tense has a separate count from *talked* used as a past participle. All analyses were carried out on the natural logarithm of each raw frequency count, which was first augmented by 1 to avoid ln(0). The irregular verbs had higher past tense frequencies than the regular verbs, according to independent measures *t*-tests (FK: $t(34) = 4.277$, $p = .0001$; AP: $t(34) = 3.561$, $p = .001$).

The verbs were selected according to six criteria. First, the real verbs were chosen to cover relatively wide stem and past tense frequency ranges. Second, we avoided verbs which can play the role of auxiliary or modal (*do, be, have*). Third, we eliminated verbs which were judged to be possible denominals (derived from a noun: $ring_N \rightarrow ring_V$), de-adjectivals (derived from an adjective: $clean_A \rightarrow clean_V$), or verbs of onomatopoeic origin ($miaow_V$). Fourth, an attempt was made to avoid real verbs whose stems or past tense forms were phonologically or orthographically identical or similar to other real words. Thus we avoided *rend*, whose irregularized past tense *rent* exists as a distinct word. Fifth, we attempted to avoid stems with ambiguous pronunciations; thus we excluded verbs like *blow*, whose orthography is similar to both *flow* and *allow*.

All verbs were presented in the context of two sentences, such as "Every day I *rob* a bank. Just like every day, yesterday I _____ a bank" (the "verb presentation sentence" and "past tense sentence", respectively). All sentences were written to conform to several criteria, with the goals of ensuring consistency among the items and facilitating the task for the aphasic subjects. First, every verb presentation sentence began with "Every day ", while every past tense sentence began with "Just like every day, yesterday." Both sentences used the first person singular subject "I." Second, all verbs were followed by a two-word complement or adjunct; both words were selected to be underived and of relatively high frequency. The same two-word complement or adjunct followed both the verb presentation and past tense sentences for a given verb. Third, the two-word complements or adjuncts for novel verbs were chosen to minimize the possibility that the subject would inflect the novel verb by conscious analogy to an existing similar-sounding verb. For example, we avoided arguments for the novel verb *brop* that might remind the subject of *drop*; thus sentences like "Every day I *brop* a penny" were excluded. Fourth, we avoided the alveolar stops [t] and [d] in the onset of the first word of each complement or adjunct, in order to increase the chance of our identification of any word-final alveolar stops produced by the subjects. Tables 3 and 4 contain a full list of verbs, together with their complements or adjuncts.

Procedure

The items were randomized by computer program (Perlman, 1986), and then gone over by hand to ensure that similar-sounding verb forms did not follow each other too closely. All subjects received items in the same order; this was done for testing convenience. Subjects were tested individually. The subject was first given several practice items, for which he or she was asked to read each sentence pair out loud, filling in the missing word. Each sentence pair was printed on a single sheet of paper in large font. The verb stem in the verb presentation sentence was displayed in boldface. If the subject misread the verb stem, he or she was stopped and asked to read the verb presentation sentence again. If reading was laborious, both sentences were read by an experimenter, with appropriate intonation to elicit a response for the missing word. All sessions were audio-taped. During the testing of each subject, a native English-speaking experimenter wrote down all responses for each verb item. If any response was unclear, or if the experimenters disagreed about a response, the tape was played back until a consensus was reached. Special attention was paid to weak final consonants such as the final [t] in *looked* and *kept*.

Transcribed responses were coded as follows. An item was counted as correct if the *first response* it elicited was correct, independent of whether this response was followed by any incorrect responses. Note that this criterion for error coding is different from the one used in Ullman (1997b), in which some of the response data analyzed here was also presented. In that paper, an item was counted as correct only if there were no errors in any of the responses for that item. This strict criterion was selected because it yields a greater error rate, and therefore greater variance, which was important because other impaired populations discussed in the paper (e.g., patients with Parkinson's disease) made very few errors. In the present paper we only discuss aphasic patients, who have very high error rates, and thus coding based on the first response is preferable for avoiding floor effects.

For real regular and irregular verbs (*look, dig*), their past tense forms (*looked, dug*) were counted as CORRECT, and all other responses were tabulated as incorrect. For novel regular verbs (*spuff),* only regularizations (*spuffed*) were counted as correct. For novel irregular verbs (*crive*) there is no single correct past tense. Regularized (*crived*) and irregularized (*crove*) past tense forms were tabulated separately as two types of correct forms. Responses were counted as REGULARIZATIONS of novel irregulars if the verb stem was *–ed*-suffixed (*crived*). Responses were counted as IRREGULARIZATIONS of novel irregulars if we judged their stem-past transformations to be phonologically similar to stem-past transformations of one or more real irregular verbs (*crive-crove,* cf. *drive-drove, dive-dove*).

First-response errors were coded, and were categorized into several types. Those responses which repeated the presented stem, for all verb types (e.g., *look-look, keep-keep, spuff-spuff, crive-crive*) were classified as UNMARKED. *–Ed*-suffixed stems of existing irregular verbs (e.g., *digged, keeped*) were classified as OVER-REGULARIZATIONS. Responses with more than one instance of the *–ed*-affix attached to the presented stem, irrespective of the type of verb (e.g., *look-lookeded, keep-keepeded, spuff-spuffeded, crive-criveded*) were coded as MULTIPLY-SUFFIXED forms. Existing irregular past tense forms with an attached *–ed* affix (e.g., *dugged*) were coded as SUFFIXED IRREGULARS. Novel irregulars which were both irregularized and *–ed*-suffixed (e.g., *crive-croved*) were classified as SUFFIXED IRREGULARIZATIONS. Existing irregulars for which a past tense form was produced that was different from the correct one but whose morphophonological transformation was similar to that of one or more other irregulars (e.g., *think-thank, fling-flang,* cf. *sink-sank, sing-sang*) were classified as OVER-IRREGULARIZATIONS. Existing and novel regulars for which a past tense form was produced that was a likely irregularization (e.g., *prap-prup*) were classified as IRREGULARIZATIONS. Forms where the *–ed*-suffix was incorrectly syllabified, and was attached to the presented stem (e.g., *look-look-id, keep-keep-id*), were coded as SYLLABICALLY-SUFFIXED. Those responses in which an *–ing*-affix was added to the presented stem (e.g., *bend-bending*) were coded as *–ING*-SUFFIXED, for all verb types. Responses in which an *–ing*-affix was added to a verb stem different from the presented one (e.g., *cook-tooking, dig-sinking*) were coded as*–ING*-SUFFIXED SUBSTITUTIONS. Responses in which an *–en*-affix was added to the presented stem (e.g. *bite-bitten, make-maken*) were coded as-*EN*-SUFFIXED. Responses in which an *–en*-affix was added to a stem different from the presented one, irrespective of verb type, were coded as*–EN*-SUFFIXED SUBSTITUTIONS (e.g., *speak-smoken*). Responses in which the 3rd person singular *–s*-affix was added to the presented stem (e.g. *show-shows*) were coded as-*S*-SUFFIXED. Responses in which the *s*-affix was added to a stem different from the presented one, irrespective of verb type, and which were plausible verbal forms (e.g., *view-vows*) were coded as*–S*-SUFFIXED SUBSTITUTIONS. Responses which were real words – verbs, nouns, or adjectives - but whose stem was not the one presented as a stimulus, and which were not *–ing, -en,* or verbal *–s*-suffixed, were classified as WORD SUBSTITUTIONS. Responses were categorized as verbal *–s*-suffixed (i.e., *–S*-SUFFIXED SUBSTITUTIONS) if we judged them to be more likely to be used as verbs than nouns (e.g., *view-vows*); otherwise they were categorized as nominal *–s*-suffixed (e.g., *flow-flowers*) and included under WORD SUBSTITUTIONS. Examples of word substitutions include uninflected words (e.g., *blide-blind, mar-mob, strink-stroke*), irregularly inflected words (e.g., *feed-fled, bend-spent, slam-shut, rush-ran*), or forms affixed with suffixes other than *-ed,–ing,* or 3rd person singular *–s* (e.g., *flow-flowers*). As evident from the above examples, word substitutions tended to be phonologically and/or semantically similar to the presented stem, but in principle, they could also be unrelated (e.g., *shrim-strut*). Responses which substituted the presented stem for a different stem, and were *–ed*-suffixed, were labeled as WORD INTRUSIONS. Some examples are *stir-sterned, frink-freaked, plam-planned.* Incorrect responses whose stem was not the one presented as a stimulus and which were not real words , and which, moreover, were not *–ed*-suffixed, were classified as DISTORTIONS. (None of the aphasic or control subjects produced *–s*-suffixed or *–in*g-suffixed distortions.) Typically, distortions were phonologically very similar to the presented stimulus and/or the target past tense. Examples include *swing-swin, keep-kep,drive-drovbe, shreep-shroke*. Distortions which were –*ed*-suffixed were labeled as –ED-SUFFIXED DISTORTIONS (e.g., *stoff-stroffed,drite-strited,shrug-shrudged*). Failures to respond and answers such as "I don't know", "no", etc. were coded as NO RESPONSE. Remaining responses which were unacceptable as well-formed words were coded as OTHER. These included isolated suffixes (e.g., *ing*); spelled-out forms (e.g. *prass - p-r-a-s-t*); isolated consonants that were either distinct from the ones found stem-initially in the presented stimulus (e.g. *sl…cling*), or if the same as those in the presented stimulus, then isolated from the response by a pause of more than a second; and consonant-vowel sequences that were an attempt to pronounce the response (e.g., *steeze - sto…stoze*).

Results and Discussion

Non-Fluent Aphasia

We tested two non-fluent aphasics who were able to perform the past tense production task. An additional five non-fluent aphasics were tested, but none was able to carry out the task. All five had frontal lesions which extended to temporal or temporo-parietal areas. Two of these five (CIG, WRO) were successfully tested on the past tense reading task.

A Non-Fluent Aphasic with a Circumscribed Anterior Lesion: FCL

We tested one non-fluent aphasic, subject FCL, whose scan indicated that the lesion was circumscribed to left anterior regions, including frontal, insular, and basal ganglia structures, and did not impinge upon temporal or temporo-parietal regions. See Tables 1 and 2 and the Appendix for demographic and additional behavioral and lesion data. Figure 1 shows the approximate extent of his cortical damage.

FCL's scores were compared to those of a group of 12 age- and education-matched control subjects (see Subjects section), using the method reported by Tukey (1977). It was determined whether FCL's response rate for a given verb class (e.g., irregulars) fell more than 1.5 interquartile ranges (1.5 times the distance between the 25th and 75th percentiles) below the 25th percentile score (i.e., for irregulars) of his control subjects. This point (the "lower fence") is used as a cutoff below which points are designated as "outliers" (Tukey, 1977). The identification of outliers using this approach does not assume a normal distribution, and therefore is quite robust.

FCL was severely impaired at producing past tense forms for real and novel regular verbs (see Table 5). His production of 4 real regular past tenses (*scowled, scoured, dropped, stirred*), which yielded a score of 20% correct, was 68 percentage points below his control subjects' lower fence for real regulars. Similarly, his production of only one novel regular past tense form (*scurred*) yielded a score of 5% correct, which was 76 percentage points below his control subjects' lower fence for novel regulars. In contrast, his score of 69% correct for real irregulars was only 16 percentage points below his controls' lower fence. His lack of irregularizations of novel irregular verbs (*crive-crove*) matched the control subjects' lower fence of zero. His 5 regularizations of novel irregulars (*crived, trined, preeded, cleeded, blided*) yielded a score of 28%, which was slightly above the controls' lower fence for this type of form (21%); however, he produced significantly fewer such forms than his control subjects (28% vs. mean of 58%; paired $t(34) = 2.076$, $p = .046$, with items as the error term). (In this paper all reported *p*s for *t*-tests are two-tailed, unless otherwise indicated.)

A 3X2 χ^2 test over irregulars, regulars and novel regulars was statistically significant ($\chi^2(2) = 18.82$, $p<.001$). FCL was significantly more successful at producing irregular than regular past tense forms (e.g., *dug* vs. *walked*; 69% vs. 20%; independent measures $t(34) = 3.29$ $p = .002$, with items as the error term). The control subjects showed the opposite pattern, performing better at regulars than irregulars, although this difference was not significant (98% vs. 96%; $t(11) = 0.96$, $p = .358$, over subjects; $t(34) = 1.00$, $p = .326$, over items). FCL was also more successful at producing real irregular than novel regular past-tenses (e.g., *dug* vs. *plagged*; 69% vs. 5%; independent $t(34) = 5.29$ $p < .0001$, over items). The control subjects did not show this pattern (96% vs. 95%; paired $t(11) = .583$ $p = .571$, over subjects). In contrast to FCL's worse performance at real and novel regulars than irregulars, his production rates of real and novel regulars (e.g., *walked* vs. *plagged*) were not statistically significantly different ($t(38) = 1.44$ $p = .159$). He produced no over-regularizations (*digged*), despite ample opportunity to do so, given that 31% of his irregular items yielded errors. In contrast, the control subjects did over-regularize (0.5% of items, 14% of errors), despite their small number of errors on irregulars (4% of items).

FCL's impaired performance at producing regular past tense forms, as compared to irregular past tense forms, might be explained by the irregular items' higher past tense frequencies: If both past types were retrieved from memory, the more frequent irregular past tense forms should be easier to produce. However, when we held past tense frequency constant in Analyses of Covariance (ANCOVAs), FCL still performed significantly better on irregular than on regular verbs (FK frequency count: $F(1,33)=8.64$ $p = .006$; AP frequency count: $F(1,33)=10.65$ $p = .003$). This indicates that FCL's superior performance on irregulars is not explained by frequency differences between regulars and irregulars.

It could also be argued that regulars are more difficult to articulate than irregulars, because these monosyllabic words' codas — the postvocallic element(s) in the syllable — often contain more consonants (e.g., *looked* vs. *dug*). Therefore the articulatory impairments typically found in Broca's aphasics (Alexander, 1997; Goodglass, 1993) might lead to more errors producing regular than irregular past tense forms, and in particular to a simplification of final consonant clusters, yielding unmarked forms (e.g., *look* instead of *looked*). FCL's production rates of 30% unmarked forms on real regulars and 30% on novel regulars would be consistent with such a view. However, several lines of evidence argue against such an articulatory account. First, there were no phonological simplification errors among the irregulars: FCL never produced forms like *keep-kep, bend-ben*, or *send-sen.* Moreover, FCL's production of unmarked irregulars (*keep*) could not be explained by such an articulatory account. To further test this alternative explanation, we analyzed a subset of the regular items. We excluded those verbs whose stems end in a stop (e.g. *tug, chop*), because in the past tense these verbs' codas contain consonant clusters that may be particularly difficult to articulate (e.g., in *tugged, chopped*). The resulting group of 10 regulars (*scowl, flush, cram, mar, scour, slam, cross, rush, stir, soar*) yielded only 3 correct responses (30% vs. the 69% correct on irregulars; independent $t(24)=2.00$, $p = .057$).

The results presented above indicate that FCL was impaired at producing *–ed*-suffixed forms, of real and novel regulars and in over-regularizations, but was relatively spared at producing irregular past tense forms. The findings suggest that this dissociation is not explained by frequency or articulatory differences between the regular and irregular test items. The dissociations appear to be best accounted for by an impairment in the knowledge or processing of an *-ed*-suffixation rule and by a relative sparing of the knowledge and processing of lexically stored irregular past tense forms.

This conclusion is further strengthened by FCL's pattern of word-substitution errors; i.e., the production of words that are morphologically unrelated to the prompted verb (e.g., Every day I *rush* after Albert. Yesterday I ____ → "*ran* after Albert"). He made five such errors: *rush-ran, drite-swam, frink-fret, shrell-squeeze, shrim-strut*. The two substitutions that were irregular verbs were past tense forms (*ran, swam*), whereas the three that were regular verbs were stem forms (*fret, squeeze, strut*). Thus even among substituted forms, irregular past tenses were more successfully produced than regular past tense forms.

[Table 5 around here]

A Non-Fluent Aphasic with a Less Circumscribed Lesion: RBA

Non-fluent aphasics with less circumscribed lesions, that extend from left anterior to left posterior regions, may show impairments to lexical as well as grammatical processes. Therefore their dissociations may be less clear than those of aphasics with more circumscribed lesions. We tested one non-fluent aphasic, subject RBA, with such a lesion. See Tables 1 and 2 and the Appendix for demographic, behavioral, and lesion data.

RBA was severely impaired at producing regular past tense forms. Like FCL, his score of 20% correct was 68 percentage points below his control subjects' lower fence. He was also highly impaired at irregulars, with a score of 25%, 60 percentage points below his control subjects' lower fence. He was worse at producing regulars than irregulars, although this difference was not statistically significant (20% vs. 25%; independent $t(34) = 0.35$, $p = .729$). The control subjects showed the opposite pattern (see above, under FCL). He was unable to perform the task for novel verbs. He produced only two over-regularizations, despite his many opportunities to do so, given that 75% of his irregular items yielded errors.

RBA's deficit on regulars was underscored by his reaction times. These were acquired during testing by an experimenter, who counted the seconds from the blank in the past tense sentence (e.g., "Just like every day, yesterday I ____") until RBA's first response. RBA took an average of almost four times as long to produce correct regulars than correct irregulars, with the difference approaching statistical significance (6.5 seconds vs. 1.75 seconds; independent $t(6) = 2.06$, $p = .086$). Because we predicted greater difficulty with regular than irregular forms, it is justifiable to report *p* as one-tailed ($p = .043$). The pattern also held when the verbs' past tense frequencies were co-varied out, with the regular/irregular reaction time differences being marginally significant (FK frequency count: $F(1,5) = 2.31$, $p = .095$, one-tailed; AP frequency count: $F(1,5) = 2.36$, $p = .093$, one-tailed).

This pattern of behavior suggests that RBA did indeed have more trouble computing regular than irregular past tenses, but that he made a greater effort at regulars, and thereby succeeded at improving his performance on this verb type. It is interesting to note that he performed similarly in a sentence-picture matching task probing his syntactic abilities in the comprehension of active and passive sentences. Although he achieved 90% performance at *both* sentence types, he performed very differently on the two types. On passive sentences, which may require greater syntactic resources than active sentences (see Kolk, 1998; Zurif, 1995), he consistently asked for the sentence to be repeated. He would also point to the characters in the picture while the sentence was being read, in an apparent effort to follow who was doing what to whom. Even then his responses were tentative. In contrast, he produced quick and confident answers to active sentences, usually on the first reading (Zurif, personal communication). Thus in both morphology and syntax, in both expressive and receptive contexts, RBA showed more effortful performance on tasks requiring more grammatical resources.

Fluent Aphasia

The past tense production task was given to 6 fluent aphasic subjects: JLU, HFL, JHA, JMO, WBO, APE. Unlike the non-fluent aphasics, all of them successfully completed the task. One of these aphasics (JLU) had a lesion which was circumscribed to left temporal and temporo-parietal regions, and did not involve frontal or basal ganglia structures. Figure 1 shows the approximate extent of his cortical damage. The other 5 patients had less circumscribed lesions which extended to frontal areas and/or the basal ganglia. See Tables 1 and 2 and the Appendix for demographic, behavioral, and lesion data.

[FIGURE 1 about here]

[FIGURE 2 about here]

<u>A Fluent Aphasic with a Circumscribed Posterior Lesion: JLU</u>

JLU was severely impaired at producing real and novel irregulars, but was relatively spared at the production of -*ed*-suffixed forms (see Table 5 for details). His real irregular past tense production rate of 63% was 30 percentage points below his control subjects' lower fence. He was significantly worse than his control subjects at producing irregular past tense forms (63% vs. 98%; paired $t(15) = 2.89$, $p = .011$, over items). He produced no novel irregularizations (e.g., *crive-crove*). In contrast, his production rate of regularizations of novel irregulars (*crived*) was higher not only than his control subjects' lower fence, but also higher than their *mean* score of this past tense type. Similarly, his score on novel regulars was above his controls' lower fence. His performance at existing regulars (90%) was slightly (9 percentage points) below his control subjects' mean score; this difference was not significant (90% vs. 99%; paired $t(19) = 1.45$, $p = .164$, over items).

He was significantly worse at producing past tense forms for irregulars than for regulars (independent $t(34) = 2.03$, $p = .050$, over items), despite the higher frequencies of the irregular past tense items in the task. The control subjects had similar production rates for irregulars and regulars (98% vs. 99%; paired $t(7) = .716$, $p = .497$, over subjects; independent $t\ (34) = .793$, $p = .433$, over items).

JLU's performance pattern suggesting a facility at producing -*ed*-suffixed forms, and an impaired lexical memory, was also reflected in his errors. Of his 6 errors on irregular items, 3 were over-regularizations (*clinged, wringed, maked*), suggesting intact –*ed*-suffixation. Two others were *dig-dung* and *think-thank*, which are consistent with a dysfunctional associative memory. (The third irregular error was a false start.) All four of his errors on novel regular verbs were -*ed*-suffixed forms (*slub-slopped, trab-trapped, pob-probbed, scash-scatched*). These included two -*ed*-suffixed distortions (*probbed, scatched*), which could not have been memorized because they are not existing words, suggesting intact rule-based computation. Finally, he produced two doubly suffixed forms (*scowl –scowleded, stir-stirreded*) (though the former was not his first response), which, like the suffixed -*ed*-suffixed distortions, could not have been memorized.

These results reveal that JLU had greater difficulty producing real and novel irregulars than -*ed*-suffixed past tense forms. In addition, he had relatively fluent and grammatical speech, but was afflicted with word-finding difficulties, both in his spontaneous speech, and as evidenced by his Boston Naming Test (Goodglass, Kaplan, & Weintraub, 1983) score (see Appendix). These findings suggest that the irregular/regular dissociation may be best explained by an impairment of the knowledge or processing of irregulars and other lexical forms stored in memory, and a relative sparing of the use of –*ed*-suffixation and other grammatical rules.

<u>Five Fluent Aphasics with Less Circumscribed Lesions</u>

We replicated JLU's pattern with a larger sample of five additional fluent aphasics with less circumscribed lesions: patients HFL, JHA, JMO, WBO, and APE. These lesions always involved temporal or temporo-parietal regions, but had extensions to frontal or basal ganglia structures. Therefore the subjects may be expected to show impairments in grammatical as well as lexical functions.

[Table 6 about here]

The interaction between Aphasia/Control and Irregular/Regular Verb approached statistical significance (F(1,11) = 3.04, p = .109, over subjects; F(1,34) = 3.37 p = .075, over items). The fluent aphasics had significantly greater difficulty producing irregulars than regulars (paired *t*(4) = 6.19, *p* = .003, over subjects ; independent *t*(34) = 2.00 *p* = .053, over items). The control subjects' rates on irregular and regular verbs did not differ significantly (98% vs. 99%; paired t(7)=0.72 p =.497, over subjects; independent t(34)= 0.79, p = .433, over items). All five aphasic subjects showed the pattern (see Table 6). The differences for two were statistically significant or approaching significance (HFL: p = .027; JHA: p = .064; JMO: p = .410; WBO: p = .410; APE: p = .410; *p*s reported as one-tailed, from independent measures *t*-tests). The aphasics produced more over-regularizations (range 0%-13% of responses, 0%-100% of errors) than their controls, who produced none (mean 5% vs. 0%; independent t(11) = 2.78, p = .018, over subjects; paired *t* (15)=1.73 *p* = .104, over items).

The four aphasics able to perform the task for novel verbs were also impaired at producing irregularizations of novel irregulars (e.g., *crive-crove*). As a group, they produced irregularizations at a lower rate than their control subjects (mean 17% vs. mean 29%). This difference was significant with items as the error term (paired t(17) = 2.43, p =.027). Although it was not significant with subjects as the error term (independent *t*(10) = 1.18, *p* = .267), all four subjects produced irregularizations at a lower rate than the mean of their control subjects. In contrast, the aphasics showed a less striking impairment in their production of regularizations of the same novel irregular verbs (e.g., *crive-crived*). As a group, their production rate of regularizations was not statistically significantly less than that of the control subjects (53% vs. 64%), with subjects as the error term (independent *t*(10) = 0.95 , *p* = .367), and only approached significance with items as the error term (paired t(17) = 2.05, p = .057). One of the four subjects produced more regularizations than the mean of the controls (67% vs. 64%), and two others produced only slightly fewer (61% vs. 64%). In addition, the aphasics produced a large number of *–ed*-suffixed errors, including *-ed*-suffixed distortions (*trine-drined*), syllabically-suffixed forms (*blide-blide-id*), and multiply-suffixed forms (*sheel-sheeleded*) (see Table 6). The combination of these errors and the correctly *-ed*-suffixed stems (*crived*) yielded production rates of all suffixed novel irregular forms. For the four aphasics, these constituted 61% of their responses for novel irregulars. Importantly, their rate at producing such forms did not differ from that of the control subjects (61% vs. 67%; independent t(10) = 0.468, p = .650, over subjects; paired *t*(17) = 1.04, *p* = .315, over items). Thus the fluent aphasics were impaired at their production of irregularizations, but produced a similar number of *–ed*-suffixed forms as their control subjects.

On balance, these findings indicate that, even in fluent aphasics with less circumscribed lesions, the production of real and novel irregulars is more impaired than is the production of *–ed*-suffixed forms. The results strengthen the double dissociation between non-fluent and fluent aphasia, underscore a role for left posterior structures in lexical memory, and strengthen the hypothesis that structures in this region are not particularly important for *–ed*-suffixation.

[Table 7 around here]

Non-Fluent vs. Fluent Aphasia

We directly compared the performance of the non-fluent and fluent aphasics with circumscribed lesions (that is, FCL vs. JLU). The ANOVA between Non-Fluent/Fluent Aphasia and Regular/Irregular Verb (e.g., *walked* vs. *dug*) yielded a significant interaction ($F(1,34) = 11.61$, $p < .005$). It also yielded a significant main effect for patient group ($F(1,34) = 8.11$, $p = .007$), but not for verb type ($F(1,34) = 1.48$, $p = .233$). A similar result was obtained from the ANOVA between Non-Fluent/Fluent Aphasia and Novel Regular/Real Irregular Verb (e.g., *plagged* vs. *dug*). This yielded a significant interaction ($F(1,34) = 15.73$, $p < .0005$), a significant main effect for patient group ($F(1,34) = 11.26$, $p < .002$), and a significant main effect for verb type ($F(1,34) = 6.47$, $p = .016$).

The significant interactions further strengthen the hypothesis that past tense *–ed*-suffixation is more dependent upon left anterior than left posterior structures, whereas irregular past tense formation is more dependent upon left posterior than left anterior regions. The main effects of group shows that the non-fluent aphasics are worse overall at the past tense production task. This is consistent with the view that at least some aspect of syntactic processing, which is necessary for the computation of inflection regardless of morphological type, is impaired in non-fluent aphasia, but largely spared in fluent aphasia. This perspective is strengthened by the fact that of the seven non-fluent aphasics who were given the past tense production task, five were unable to perform it at all, whereas all six fluent aphasics who were given the task were able to carry it out. The lack of a main effect of verb type for real regulars and irregulars shows that, over non-fluent and fluent aphasia, neither verb type is more difficult than the other.

We also compared the two non-fluent aphasics' and six fluent aphasics' distortion errors (e.g., for *dig*, uttering *cug* or *lig*). The ANOVA between Non-Fluent/Fluent Aphasia and Regular/Irregular Verb Distortion yielded an interaction ($F(1,34) = 3.88$, $p = .057$, over items; analysis over subjects was not performed because of the small sample size of the non-fluent aphasic group). On irregular verbs, the fluent aphasics produced more distortions than the non-fluent aphasics (5% vs. 0%; paired $t(15) = 2.61$, $p = .020$, over items) — even though the fluent aphasics had fewer opportunities to make errors, because their performance at irregulars was better than that of the non-fluent aphasics (71% vs. 47%). In contrast, on regular verbs the fluent and non-fluent aphasics did not differ in the number of distortions produced (fluent 1% vs. non-fluent 3%; paired $t(19) = 0.62$, $p = .541$, over items). Moreover, whereas the six fluent aphasics produced significantly more distortions on irregular than regular verbs (5% vs. 1%, independent $t(34) = 2.18$, $p = .036$, over items), the two non-fluent aphasics showed the reverse trend, although the difference was not statistically reliable (3% vs. 0%, for regulars and irregulars respectively; independent $t(35)=1$ $p = .324$, over items). Thus the fluent aphasics' production of irregular verbs yielded the largest number of distortions.

These results support the hypothesis that the computation of irregular past tenses depends on phonological representations in associative lexical memory, which are impaired in fluent aphasia and relatively spared in non-fluent aphasia, whereas regular past tenses are computed by a distinct rule-processing system, which is impaired in non-fluent aphasia and relatively spared in fluent aphasia: If the computation of irregular inflection involves access to two stored forms (stem and past tense), whereas the computation of regular inflection need only involve one (stem), impairments of lexical memory (in fluent but not non-fluent aphasia) that lead to distortions are more likely to be observed in the computation of irregular than regular forms.

STUDY 2: PAST TENSE READING

Method

Materials

Seventeen regular past tense forms were item-matched to 17 irregular past tense forms on past tense syllable structure and on the frequencies (Francis & Kucera, 1982) of their stem (unmarked) and past-tense forms. The regular and irregular items were not statistically significantly different in their ln-transformed stem frequencies (FK: $t(16)=.48$ $p = .637$; AP: $t(16) = .16$, $p = .879$) or past tense frequencies (FK: $t(16)=1.03$ $p = .318$; AP: $t(16) = .44$, $p = .667$), as measured by paired *t*-tests. See Table 8 for a list of the items and their mean frequencies.

[Table 8 about here]

Procedure

Each subject was tested individually, and received the 34 past tense items in randomized order on sheets of paper. The subject was asked to read the items out loud. No time constraints were imposed, and the subject was allowed to try again immediately if he or she so desired. No feedback was given. An answer was scored as correct if the correct past tense form was uttered as the first response. A subset of the subjects were also asked to read out loud the stems (unmarked forms) of the 34 verbs. For these subjects, the stem items were intermixed with the past tense items. Errors at both past tense reading and stem reading were based on first responses, and were categorized according to the same error types as were used in the past tense production task.

Results and Discussion

Non-Fluent Aphasia

Nine non-fluent aphasics successfully carried out the past tense reading task: FCL, CIG, WRO, LDO, PJ, KCL, NSL, HTA, and NWH (see Tables 9 and 12). One additional non-fluent aphasic subject (BMC) was not able to perform it. For the 9 aphasics, the interaction between Aphasic/Control and Regular/Irregular Past-Tense was statistically significant ($F(1,15) = 11.021$, $p < .005$, over subjects; $F(1,16) = 9.38$, $p = .007$, over items). The control subjects had similar scores at reading irregular (99%) and regular (100%) past tense forms. In contrast, the aphasics were more accurate at reading irregulars than regulars (51% vs. 31%; see Tables 9 and 12): paired $t(8) = 3.438$, $p = .009$, over subjects; paired $t(16)=3.27$, $p < .005$, over items. Seven of the 9 subjects showed this pattern of better performance at reading irregular than regular past tense forms. The difference was statistically significant for five of them (CIG: $p = .021$; LDO: $p = .004$; PJL: $p = .015$; KCL: $p = .004$; WRO: $p = .028$), was approaching significance for another (NWH: $p = .094$), and was not statistically significant for the last (FCL: $p = .249$), as measured by paired *t*-tests over items, with *p*s reported as one-tailed (which is justifiable because we predicted the observed pattern). The remaining two subjects (NSL, HTA) did not differ in their ability to read regular versus irregular past tense forms: Both subjects showed the same pattern (29% vs. 24% correct, paired $t(16) = 0.37$, $p = .718$).

[Table 9 about here]

In the study of reading aloud, it has been shown that words whose orthography-to-phonology mappings are distinct from those of other words (i.e., “exception” words such as *yacht*) or that conflict with those of other words (i.e., “inconsistent” words, such as *pint*; c.f. *mint, lint, dint*, etc.) can be more difficult to read than words with more “consistent” mappings, such as *kick* (c.f., *lick, stick, flick*, etc.) (e.g., see Plaut et al., 1996). In particular, certain patients have more trouble with exceptional and inconsistent than consistent words (see Coltheart et al., 1993; Plaut et al., 1996) (Intriguingly, it appears that patients do not show the opposite pattern, once factors such as word frequency and word length are held constant (Friedman, 1998; Plaut, 1998).) Thus a difference between the regular and irregular past tense items in orthography-to-phonology consistency could explain the observed regular/irregular reading differences. The regulars were indeed more inconsistent than the irregulars. The 17 regulars and 17 irregulars had similar numbers of "neighboring friends" — that is, words with a similar orthography (neighbors), whose orthography-phonology mappings are also similar (friends) (e.g., the neighboring friends of *slip* include *tip, rip, flip,* etc.): regular mean of 10.6 neighboring friends vs. irregular mean 10.9 (paired t(16) = .12, p = .909). However, the regulars had significantly more "neighboring enemies" — that is neighbors whose orthography-phonology mappings are different (enemies) (e.g., the neighboring enemies of *drove* include *move* and *love*): regular mean 3.2 vs. irregular mean 0.1; paired t (16)=2.44, p =.027. This pattern of greater spelling-to-sound inconsistency among the regular than irregular items might explain the non-fluent aphasics' observed pattern of worse performance at reading regular than irregular past tense forms.

Therefore a subset of the regular and irregular past tense forms used in the past tense reading task were matched one-to-one for spelling-to-sound consistency. The resulting groups consisted of 9 regulars (*slipped, tried, tied, died, sighed, weighed, learned, seemed, stayed*) and 9 irregulars (*swore, fled, clung, slid, bought, swept, kept, held, drove*). Both groups had an average of 10.9 neighboring friends. Similarly, the regulars had an average of 0.33 enemies and the irregulars had an average of 0.22 enemies. The regular and irregular items did not differ statistically on their number of enemies (paired t(8)=1.00, p = .347), or on their past tense frequencies (FK: paired t(8)=1.05, p = .325; AP: paired t(8)=.48, p = .645). Nevertheless, the 9 non-fluent aphasics showed the predicted pattern of having greater difficulty reading these regular than irregular past tense forms (30% vs. 50%, paired t(8) = 2.26 p = .027, over subjects; paired t(8) = 2.11 p = .034, over items, with *p*s reported as one-tailed). Seven of the nine aphasics read the irregular items more successfully than the regular items (FCL: 63% vs. 33%; p = .224; CIG: 11% vs. 0%; p = .174; WRO: 33% vs. 11%; p = .174; LDO: 78% vs. 11%; p = .011; PJ: 78% vs. 44%; p = .098; KCL: 56% vs. 33%; p = .085; NWH: 100% vs. 67%; p = .041), as measured by paired t-tests over items, with *p*s reported as one-tailed. One aphasic showed no difference (NSL: 22% vs 22%), and one showed a trend towards worse performance for irregulars (HTA: 11% vs. 44%; p=.081, two-tailed). Therefore the non-fluent aphasics' pattern of worse performance at reading regular than irregular past tense forms is unlikely to be explained by differences in the consistency of the spelling-to-sound mappings of the regular and irregular items.

It might be argued that the non-fluent aphasics' relative impairment at reading regular past tenses could be explained by a tendency to stop reading when a full word is encountered. Regular past tense forms would be unlikely to be read in their entirety because most of them contain the reading for the stem (e.g., *slipped*). In contrast, most irregular past tense forms do not contain any word-initial separate form (*swept*), and so would be read in their entirety. This hypothesis is ruled out in the case of at least one of the non-fluent aphasics. We asked the patient LDO (who showed a robust dissociation between regular and irregular forms) to read 13 words which orthographically (and in some cases morphologically) contain other words: *someone, ballplayer, children, party, mother, student, plane, salesman, traveler, postcard, everyone, banana, country*. Their ln-transformed frequencies did not differ significantly from those of the 17 regular past tense forms (FK: 3.9 vs. 3.4, t(28) = 0.93, p = .361; AP: 7.1 vs. 6.5, t(28) = 0.76, p = .452). LDO was significantly better at reading these 13 non-inflected forms (69% correct) than the 17 regular past tenses (18% correct): independent t(28) = 3.24, p = .004, over items. Moreover, the one regular past tense item that does *not* contain an embedded orthographic word (*tried*), and thus should be more likely to be read in its entirety according to this alternative hypothesis, was read incorrectly by 6 of the 9 patients.

The aphasics' errors were also very revealing. None of them produced any over-regularizations, suggesting an inability to compute *–ed*-suffixation. Errors were predominantly unmarked forms. More unmarked forms were produced for regular than irregular items (30% vs. 13%; paired $t(8) = 4.04$ $p = .004$, over subjects; paired $t(16) = 3.31$ $p = .004$, over items), even as a percentage of errors (43% vs. 27% of errors; paired $t(8) = 1.77$ $p = .115$, over subjects; paired $t(16) = 3.08$ $p = .007$, over items). This pattern is consistent with the hypothesis that a rule-computing dysfunction leads to the omission of *–ed* suffixes. This view is strengthened by the finding that other errors did not follow this pattern. Thus there were no more word substitution errors on regulars than on irregulars, either as a percentage of items (16% vs. 16%), or as a percentage of errors (23% vs. 33%; paired $t(8) = 1.66$, $p = .135$, over subjects; paired $t(16) = 0.74$ $p = .471$, over items). Similarly, the distortion rate was not reliably different for regulars compared with irregulars, both as a percentage of items (1% vs. 2%; paired $t(8) = 0.80$, $p = .447$, over subjects; paired $t(16) = 1.00$ $p = .332$, over items) and as a percentage of errors (1% vs. 4%: paired t(8) = 0.93, $p = .381$ over subjects; paired $t(16) = 1.35$, $p=.195$ over items).

Four of the non-fluent aphasics (KCL, NSL, HTA, and NWH) were also given the verb stems to read (see Tables 10 and 14). Both as a group and individually, these non-fluent aphasics had better scores on reading stems than on reading the corresponding past tense forms. For regular verbs, these four subjects read a mean of 68% of the stems correctly but only 44% of the past tense forms (paired $t(3) = 9.798$, $p = .002$, over subjects; paired $t(16) = 2.626$, $p = .018$, over items). This pattern was also observed for irregular verbs, although it was less pronounced: The aphasics read 71% of the stems correctly but 53% of the past tense forms (paired $t(3) = 2.121$, $p = .124$, over subjects, paired $t(16) = 2.219$, $p = .041$, over items). These findings indicate that the non-fluent aphasics are more impaired at reading past tense than stem forms, even for irregular verbs. These differences at reading stems and past tense forms cannot be attributed to frequency differences, because for both the regular and irregular items the stems actually had slightly *lower* FK and AP frequencies than the past tense forms (see Table 8). These data are consistent with the hypothesis that agrammatic non-fluent aphasia is associated with some type of a syntactic impairment in addition to the posited morphological suffixation impairment (independent of whether or not the two impairments have a common basis). A syntactic deficit would be expected to lead to greater difficulty computing tensed than unmarked forms, even in an isolated word reading task, whereas the morphological deficit leads to additional difficulty computing regulars (see Izvorski & Ullman, 1999)

[Table 10 about here]

These reading data show that non-fluent aphasics have more trouble reading regular than irregular past tense forms, even when controlling for word frequency, articulatory difficulty, and spelling-to-sound consistency. Moreover, a tendency to stop reading when a full word is encountered does not appear to account for the data. The results appear to be best explained by the hypothesis that non-fluent aphasia is associated with a grammatical dysfunction which impairs *–ed*-suffixation as well as syntactic computations, but leaves lexical memory relatively intact.

[Insert Figure 3 around here]

[Insert Figure 4 around here]

Fluent Aphasia

The past tense reading task was given to 5 fluent aphasic subjects: HFL, APE, LBR, RHH, and YHY. As expected, these aphasics had higher scores at reading regular than irregular past-tenses (61% vs. 55%; see Tables 11 and 12), although the difference did not reach statistical significance (paired $t(4) = 1.29$, $p =.133$, over subjects; paired $t(16) = 1.05$, *p*

=.156, over items, with *p*s reported as one-tailed). The pattern of superior performance at reading regular than irregular past-tenses held for four of the five subjects (see Table 11; APE: p=.290; HFL: p=.166; LBR: p=.166; YHY: p=.166; RHH: p=.082; *p*s reported as one-tailed, from paired *t*-tests). One subject showed the reverse pattern (LBR: p=.332, two-tailed).The control subjects showed similar performance at reading regular and irregular past tenses (99% vs. 98%; paired t(7) = 1.00, p = .351, over subjects; paired t(16) = 1.00, p = .332, over items). The ANOVA between Aphasia/Control and Regular/Irregular Past-Tense indicated the suggestion of an interaction, with subjects as the error term (F(1,11)=2.013 p=.184, over subjects), although such an interaction was not evident with items as the error term (F(1,32) = .64 p = .430).

[Table 11 about here]

[Table 12 about here]

The fluent aphasics' deficit at irregulars was , however, revealed by analyses which took into account the orthography-phonology mapping consistency of the regular and irregular past tense items. As discussed above, the regular items had more inconsistent spelling-to-sound mappings than did the irregular past tense items. Thus the finding that the fluent aphasics' predicted regular/irregular difference did not reach significance might be explained by the regulars' disadvantage in orthography-phonology consistency. This could lower the fluent aphasics' performance at reading regulars, thereby diminishing the predicted relative disadvantage of irregulars. Therefore we compared the five fluent aphasics' performance at reading the 9 regulars and 9 irregulars matched on orthography-phonology consistency and frequency (see above). As predicted, the aphasics were significantly more accurate at reading regular than irregular past-tenses (64% vs. 44% correct; paired *t*(4)=2.714 *p*=.027, over subjects; paired *t*(8)=2.00 *p*=.041, over items, with *p*s reported as one-tailed). In contrast, the control subjects showed no such difference between the 9 regulars and 9 irregulars (100% vs. 99%; paired t(7) = 1.00, p = .351, over subjects; paired t (8)= 1.00, p = .347 , over items). Four of the five aphasics showed the predicted pattern of better performance reading regular than irregular items (APE: 100% vs. 78%; p=.085; HFL: 89% vs. 44%; p=.018; LBR: 22% vs. 0%; p=.085; YHY: 89% vs. 78%; p=.174), as measured by paired *t*-tests over items, with *p*s reported as one-tailed. One aphasic showed no difference (RHH: 22% vs. 22%). These findings demonstrate that fluent aphasia is associated with a greater impairment at reading irregular than regular past tense forms, once orthography-phonology consistency is held constant.

The fluent aphasics' errors also revealed their underlying dysfunction. Like the fluent aphasics in the past tense production task, these subjects produced significantly more distortions (e.g., for *dig*, uttering *cug* or *lig*) for irregular than regular past-tenses, both as a percentage of items (22% vs. 7%; paired t(4)= 4.33, p = .012, over subjects; paired t(16) = 2.75, p = .014, over items), and as a percentage of errors (50% vs. 18%; paired t(4)= 5.62, p = .005, over subjects; paired t(16) = 3.24, p = .005, over items). This contrast dissociates irregular from regulars, and suggests that the structures damaged in fluent aphasia subserve the stored phonological forms of memorized words (see discussion above).

Three of the fluent aphasics (LBR, YHY, and RHH) were also given the verb stems to read (See Tables 13 and 14). Unlike the non-fluent aphasics, these three fluent aphasics were not reliably better at reading stems than at reading their corresponding past tense forms, for either irregular verbs (47% vs. 39%; paired *t*(2) = 1.51, *p* = .270, over subjects; paired *t*(16) = 1.29, *p* = .216, over items) or regular verbs (57% vs. 43%; paired *t*(2) = 1.75, *p* = .222 over subjects; paired *t*(16) = 1.95, *p* = .069, over items). This suggests that in fluent aphasia, unlike in non-fluent aphasia, the syntactic mechanisms underlying the computation of tense may be largely spared.

[Table 13 about here]

[Table 14 about here]

In summary, the reading data show that fluent aphasics have greater difficulty reading irregular than regular past tense forms, when past tense frequency and spelling-to-sound consistency are controlled for. The findings are consistent with the claim that left posterior structures damaged in the present cases of fluent aphasia underlie lexical memory, and do not play an important grammatical role either in affixation or in the syntactic computation of tense.

Non-Fluent vs. Fluent Aphasics

We directly compared the performance of the non-fluent and fluent aphasics. The ANOVAs between Non-fluent/Fluent Aphasia and Regular/Irregular Past-Tense yielded statistically significant interactions ($F(1,12) = 9.23$, $p = .010$, over subjects; $F(1,32) = 9.53$, $p < .005$, over items). There was an inconsistent main effect for patient group ($F(1,12) = 1.18$ $p = .299$, over subjects; $F(1,32) = 16.31$, $p < .0005$, over items), but no significant main effect for verb type ($F(1,12) = 2.86$, $p = .117$, over subjects; $F(1,32) = 2.21$, $p = .147$, over items).

The significant interactions strengthen the view that, even in reading isolated words, non-fluent aphasia impairs the computation of *–ed*-suffixed past tense forms, whereas fluent aphasia impairs the computation of irregular past tenses. The results further strengthen the view these two functions are linked to left anterior and left posterior regions, respectively.

The non-fluent and fluent aphasics' pattern of errors was also revealing. The ANOVA between Non-fluent/Fluent Aphasia and Distortions on Regular/Irregular Verb was statistically significant ($F(1,12) = 17.10$ $p = .001$, over subjects; $F(1,16) = 5.56$ $p = .031$, over items). We reported above that the fluent aphasics produced significantly more distortions for irregulars than for regulars, whereas the non-fluent aphasics did not show this pattern. Moreover, for irregulars, the fluent aphasics produced significantly more distortions than the non-fluent aphasics (22% vs. 2%; independent $t(12)=3.37$, $p = .006$, over subjects; paired $t(16)=4.09$, $p = .001$, over items). For regulars, the fluent aphasics produced only borderline significantly more distortions than the non-fluent aphasics (7% vs. 1%; independent $t(12) = 1.83$, $p = .093$, over subjects; paired $t(16)= 2.06$, $p = .056$, over items). These results largely replicate the pattern of distortions for regulars and irregulars produced by the two types of aphasics in the past tense production task. They further strengthen the hypotheses that irregular but not regular past tense forms are retrieved from an associative memory representing (at least) the stored sounds of words, and that this memory is particularly dependent upon the left posterior regions damaged in fluent aphasia.

STUDY 3: PAST TENSE JUDGMENT

Method

Materials

Subjects were presented with the same 80 verbs as in the past tense production task: 20 "consistent" regular verbs, 20 irregular verbs, 20 novel regular verbs, and 20 novel irregular verbs. We excluded from analysis the four real irregular and two novel irregular verbs that were also excluded from analysis in the past tense production task. Subjects were also presented with 20 doublet verbs, which are discussed below, and 20 "inconsistent" regular verbs, which are not reported here. Four doublet verbs (*knit*, *wed*, *wet*, *thrust*) were excluded from analysis because their irregular past tense forms are identical to their stems. See Tables 3 and 4 for a list of the real and novel, regular and irregular verbs, together with the real verbs' relative frequencies. See Table 15 for analogous information for the doublet verbs.

[Table 15 about here]

As in the past tense production task, all verbs were presented in the context of two sentences, such as "Every day I *rob* a bank. Just like every day, yesterday I *robbed* a bank" (the "verb presentation sentence" and "past tense sentence", respectively). Each verb was presented in the same sentence pair that was used in the past tense production task. The only sentence presentation difference between the two tasks was that in the judgement task a verb form rather than a blank was presented in the past tense sentence.

All verbs were presented twice, both times in the same sentence pair context. For most verb types, 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 consistent regular and novel regular verbs (e.g., Just like every day, yesterday I *rob* a bank"). For irregular verbs, it was the over-regularized form (e.g., Just like every day, yesterday I *digged* a hole). For novel irregular verbs, subjects were shown the regularized form (e.g., *crived*) in one presentation, and a plausible irregularized form (*crove*) in the other. Similarly, for doublet verbs, subjects were should both the doublet regular (*dived*) and doublet irregular (*dove*).

Procedure

The items were randomized by computer program (Perlman, 1986), and then gone over by hand to ensure that the two forms of the same verb (e.g., *dug* and *digged*), or similar-sounding verbs (e.g., *swing* and *cling*), did not follow each other too closely. All subjects received items in the same order; this was done for testing convenience. Subjects were tested individually. Aphasic subjects were asked to give numerical ratings from 1 (worst) to 5 (best) according to how bad or good the verb in the second sentence (the past tense sentence) sounded as a past tense of the verb in the first sentence (the verb presentation sentence). Non-fluent aphasic subject BMC was unable to perform this rating scheme, and was therefore given simpler instructions, being asked to say whether the form was acceptable or not ("yes" or "no"). The forty undergraduates who served as control subjects were asked to give ratings between 1 and 10. All ratings were normalized to 0-100. Only these normalized ratings were used in our analyses and only these normalized ratings are discussed below. Control subjects read each sentence pair out loud; an experimenter read them aloud to the aphasic patients. Subjects were first given several practice items. Each sentence pair was printed on a single sheet of paper in large font. The verb stem in the verb presentation sentence, and the verb form in the past tense sentence, were both displayed in boldface. All sessions were audio-taped. During the testing of each subject, an experimenter wrote down all responses for each verb item. If any response was unclear, or if the experimenters disagreed about a response, the tape was played back until a consensus was reached. Analysis was based on the first response to each item.

Results and Discussion

The past tense judgment task was given to three agrammatic non-fluent aphasics and one anomic fluent aphasic. Data from each subject is analyzed individually below.

Non-fluent Aphasia

An Non-fluent Aphasic with a Circumscribed Anterior Lesion: FCL

The past tense judgment task was given to FCL, the non-fluent aphasic patient whose lesion was circumscribed to left anterior structures, and who also carried out the past tense production and reading tasks. As in these other two tasks, his performance in past tense judgment revealed a deficit in the computation of –*ed*-suffixation, and a relative sparing of irregulars.

The interaction between Aphasia/Control and Regular/Irregular Past-Tense was borderline significant (F(1,34) = 3.58, p = .067, over items). FCL showed the predicted pattern, with higher ratings for irregular than regular past tenses, (98 vs. 83, independent t(34) = 1.73, p = .047, with *p* reported as one-tailed). In contrast, the control subjects showed the opposite pattern, giving lower ratings to irregulars than to regulars (94 vs. 95, independent t(34) = 1.90, p = .066). On irregulars, FCL's ratings were significantly *higher* than those of his control subjects (98 vs. 94, paired t(15) = 2.78, p = .014). This can be attributed to the control subjects' wider rating scale (1 to 10), which may be expected to lead to fewer selections of perfect ratings than the smaller rating scale used by FCL (1 to 5). In contrast, on regulars FCL gave lower ratings than the controls, although the difference did not reach statistical significance (83 vs. 95, paired t(19) = 1.58, p = .130).

It is important to point out that the observed control subject pattern of higher ratings for regulars than irregulars makes it "harder" to demonstrate the opposite pattern in non-fluent aphasics. A disturbance of the hypothesized rule system in non-fluent aphasia may impair the computation of regulars, leading to lower regular ratings for non-fluent aphasics than control subjects. However, such a disturbance might still leave non-fluent aphasics' ratings for regulars no lower, or not significantly lower, than their ratings for irregulars. Thus FCL's significantly lower ratings for regulars than irregulars suggests quite a substantial dysfunction of –*ed*-suffixation.

If regulars as well as irregulars were memorized, as is predicted by a single system perspective, it could be argued that FCL's lower ratings of regular than irregular past tense items could be attributed to the fact that the regular past-tense items had lower frequencies than the irregular past-tense items. Note that this account is unlikely, given the control subjects' pattern of worse performance at irregulars than regulars. Nevertheless, we explicitly tested this alternative explanation by covarying out past tense frequency in an ANCOVA between Aphasia/Control and Regular/Irregular Past-Tense. This yielded marginally significant interactions (FK: F(1,33) = 3.06, *p* = .090, over items; AP: F(1,33) = 2.36, *p* = .134, over items). Covarying out past tense frequency, the control subjects had significantly higher ratings for regulars than irregulars (FK: F(1,33) = 15.51 *p* < .0005; AP: F(1,33) = 19.05, *p* = .0001). Despite the difficulty of overcoming this advantage of regulars, FCL showed the opposite pattern, with the difference approaching significance (FK: F(1,33) = 2.16 *p* = .076 one-tailed, over items; AP: F(1,33)=1.59 *p*=.108 one-tailed).

FCL also had particular difficulty recognizing –*ed*-suffixed novel verbs. The control subjects rated irregularizations of novel irregulars (*crove*) significantly lower than novel regular past tenses (*plagged*) (66 vs. 85, independent t(36) = 9.87, p < .001, over items), and marginally worse than regularizations of novel irregulars (*crived*) (66 vs. 72; paired t(17) = 1.69, p = .109, over items). FCL did not show this pattern. His ratings of irregularizations of novel irregulars (*crove*) were not significantly lower than his ratings of novel regular past tenses (*plagged*) (21 vs 26; independent t(36) = 0.50, p = .624, over items), or of regularizations of novel irregulars (*crived*) (21 vs. 32; paired t(17) = 0.91, p = .374, over items).

FCL appeared to have trouble recognizing over-regularizations. Although he gave similar ratings as his controls to over-regularizations (*digged*) (25 vs. 26; paired t(15) = 1.0, p = .925, over items), of the four over-regularizations that he accepted (ratings above 50), one was rated only after a lengthy pause, and another only after the sentence pair was repeated by the experimenter. Thus half of the over-regularizations that he accepted were rated after a substantial hesitation. In contrast, only one of the 16 irregulars was rated after such a hesitation. This suggests that FCL had difficulty computing over-regularized forms.

Finally, FCL failed to reject several unmarked forms of real or novel regulars in their past tense sentence contexts (e.g., Just like every day, yesterday I *flush* a toilet): *flush*, *mar*, *spuff*, and *cug*. This is consistent with a morphological failure to compute –*ed*-suffixation.

In summary, FCL gave lower ratings to regular than irregular past tense forms, appeared to have trouble computing *–ed*-suffixed novel forms and over-regularizations, and accepted unmarked forms of real and novel regulars. These results are consistent with the hypothesis that, even in past tense judgment, *-ed*-suffixed forms were difficult for him to compute, and that the computation of such forms was more impaired than the computation of irregular past tenses. This contrast further strengthens the view that the brain structures damaged in his relatively circumscribed left anterior lesion participate in the computation of morphological suffixation rules, even in the receptive task of judgment, but are less important for lexical memory. Moreover, FCL's acceptance of unmarked forms of real and novel regular verbs not only underscores the hypothesized *–ed*-suffixation deficit, but is consistent with the existence of a more general morphosyntactic deficit which affects inflection processes independent of their regular/irregular status.

Two Non-fluent Aphasics with Less Circumscribed Lesions

Non-fluent aphasics with less circumscribed lesions, extending from left frontal to left posterior regions, may show impairments to lexical as well as grammatical processes. Therefore their dissociations may be less clear than those of aphasics with more circumscribed lesions.

Patient BMC.

Non-fluent aphasic patient BMC, who failed to perform the past tense production and 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.

BMC gave ratings to 15 irregular and 8 regular past tense forms. His ratings were significantly greater than zero for irregulars (mean rating of 37; $t(14) = 2.96$, $p = .010$) but not for regulars (mean rating of 13; $t(7) = 1.00$, $p = .351$), as measured by *t*-tests of whether the sample mean differed significantly from a population mean of 0. Note that since only positive values could be obtained, this *t*-test is biased in the direction of rejecting the hypothesis that the population mean is zero, thus lending added credence to the non-significant finding for regulars. Likely because of the small sample size, the interaction between Aphasia/Control and Regular/Irregular Past-Tense was not statistically reliable, although it showed the expected trend ($F(1,21) = 1.85$, $p = .188$, over items). The control subjects had somewhat higher ratings for regular than irregular past tense forms (96 vs. 94; independent $t(21) = 1.71$, $p = .102$). Despite the difficulty of overcoming this advantage of regulars, BMC's average rating of irregular past tenses was almost three times higher than that of his regular past tenses (37 vs. 13, independent $t(21) = 1.25$, $p = 0.133$, one-tailed).

The ANCOVA between Aphasia/Control and Regular/Irregular Past-Tense, covarying out past-tense frequency, yielded a similar pattern (FK: $F(1,20) = 1.84$, $p = .190$, over items; AP: $F(1,20) = 1.59$, $p = .222$, over items). Covarying out past tense frequency, the control subjects had significantly higher ratings for regular than irregular past tense forms (FK: $F(1,20) = 11.92$, $p < .005$, over items; AP: $F(1,20) = 15.05$, $p < .001$, over items). Despite this advantage of regulars, BMC still showed the opposite pattern, with higher ratings for irregulars than regulars, although the differences were not statistically significant (FK: $F(1,20) = 1.40$, $p = .126$ one-tailed, over items; AP: $F(1,20) = 1.20$, $p = .144$ one-tailed, over items). Moreover, covarying out past tense frequency, BMC had statistically significantly lower ratings than the control subjects on regulars (FK: $F(1,6) = 6.74$, $p = .041$, over items; AP: $F(1,6) = 11.93$, $p = .014$), but not on irregulars (FK: $F(1,13) = 3.69$, $p = .077$; AP: $F(1,13) = 2.08$, $p = .173$).

BMC was unable to carry out the task for novel verb forms. This is consistent with the hypothesis that he was impaired at computing *–ed*-suffixation. His errors further strengthened this hypothesis. He gave ratings to 8 over-regularizations. His ratings on these forms were not significantly different from zero (mean of 19; $t(7) = 1.43$, $p = 0.394$).

He showed a very different pattern on the 10 unmarked forms of regular verbs that he rated (e.g., Just like every day, yesterday I *walk* along there). Their ratings were significantly greater than zero (mean of 60; t(9) = 4.13, p = .003), and were also significantly greater than the control subject's ratings of these unmarked forms (60 vs. 15; paired t(9) = 3.17, p = .011). Indeed, BMC's rating on unmarked forms were three times higher than those of his over-regularizations (60 vs. 19; independent t(16) = 2.05, p = .057), despite the fact that over-regularizations are marked for past tense, and therefore are syntactically appropriate. His acceptance of unmarked regular forms also supports the hypothesis that he suffered from some form of a more general morphosyntactic impairment. Importantly, his high ratings on the 10 unmarked regular verb-forms also show that his low ratings on the 8 regular past tense forms, and their non-significant difference from zero, cannot be simply attributed to their small sample size.

Patient RBA.

As in the past tense production task, RBA's deficit at regulars was revealed not by his error rates, but by his reaction times. The interaction between Aphasia/Control and Regular/Irregular Past-Tense was not significant (F(1,34) = 0.39, p = .583, over items). Similarly, there was no significant difference between his regular and irregular ratings (95 vs. 88; independent t(34) = 0.79, p = .433, over items). The control subjects gave borderline significantly higher ratings to regular than irregular items (see above, under FCL).

RBA's underlying deficit was revealed by his reaction times. These were acquired during testing by an experimenter, who counted the seconds from the end of the past tense sentence until RBA's first response. RBA took an average of three times as long to correctly judge (those items rated above 50) regulars than irregulars (1.8 seconds vs. 0.6 seconds; independent t(31) = 1.38, p = 0.089, one tailed). This difference held, and indeed reached statistical significance, when past-tense frequency was held constant in ANCOVAs (FK: F(1,30)=3.34 p=.039, one-tailed; AP: F(1,30)=3.86 p=.030, one-tailed).

Like BMC, RBA was unable to carry out the task for novel verb forms, as expected by an *–ed*-suffixation deficit. Such a deficit was also revealed by his ratings of incorrect forms. Whereas the control subjects gave significantly higher ratings to over-regularizations, which are past-tense marked, than to unmarked regular verb forms (26 vs. 15; independent t(34) = 6.15, p < 0.001), RBA did not show such a significant difference (34 vs. 23; independent t(34) = 0.82, p = 0.418). In addition, RBA was slower at rating unmarked forms than over-regularizations, although this difference was not statistically significant (4.3 seconds vs. 2.9 seconds; independent t(34) = 1.445, p = 0. 158). Finally, his ratings for unmarked forms were significantly greater than zero (mean of 23, t(19) = 2.49, p = 0.022). This result also supports the hypothesis that he suffered from some form of an impairment of syntactic computation.

Summary.

BMC and RBA both showed a pattern of greater difficulty rating regulars than irregulars, even when past tense frequency was controlled for. BMC showed this contrast in lower ratings for regulars than irregulars, whereas RBA showed the contrast in longer reaction times for regulars than irregulars. Both subjects gave surprisingly low ratings to over-regularizations and unexpectedly high ratings to unmarked forms. These results strengthen the conclusions drawn from FCL's judgment data: even in a receptive context, non-fluent aphasics show morphological deficits in the computation of *–ed*-suffixation, and apparently more general morphosyntactic impairments as well.

Fluent Aphasia

The hypothesized lexical impairment of fluent aphasics should lead them to have more trouble recognizing correct real and novel irregular forms (e.g., *dug, dove, crove*) than real and novel regular forms (e.g., *walked, dived, plagged, crived*), and they should accept over-regularizations (e.g., *digge*d). Because they are hypothesized to have intact morphological rule-processing, and possibly intact morphosyntax as well, they should correctly reject unmarked forms of real and novel regulars (*walk*, *plag*).

A Fluent Aphasic with a Circumscribed Posterior Lesion: JLU

Whereas the production task reported above for JLU was given to him 9 months post-stroke, the judgment task was given to him 16 months after onset. By this point his aphasia was considerably improved, as evidenced by his scores at a retest of the production task. Although this past tense production retest yielded the same pattern of greater difficulty with irregulars than regulars as was found in the first testing session (as was expected), his performance had improved (75% correct irregulars vs. 95% correct regulars). Similarly, at the judgment task his performance was at ceiling, with mean ratings of 100 for irregulars as well as regulars.

We therefore examined his judgment of doublet verbs, such as *dive-dove/dived*. The irregular past tense frequencies of these verbs are substantially lower than those of the other irregular items (see Tables 3 and 15), so JLU would be expected to be less likely to be at ceiling for judging doublet irregular past tenses (*dove*). In unimpaired control subjects, doublet regulars (*dived*) have been predicted to be stored; if they were not stored, they could be blocked (see Ullman, 1993). If fluent aphasics have impairments of lexical memory, they should have trouble remembering doublet regulars as well as doublet irregulars. They are therefore predicted to apply *–ed*-suffixation rules upon failure to retrieve either stored past tense type, although of course these "over-regularizations" would have the same surface form as doublet regulars. JLU should thus have greater difficulty recognizing doublet irregulars, which are stored, than doublet regulars, which would be successfully rule-computed, without being blocked by their corresponding hard-to-remember doublet irregulars.

The interaction between Aphasia/Control and Doublet-Regular/Doublet-Irregular Past-Tense (e.g., *dived* vs. *dove*) was significant ($F(1,30) = 13.27$, $p = .001$, over items). As predicted, JLU gave statistically significantly lower ratings to doublet irregulars than to doublet regulars (69 vs. 94; independent $t(30) = 1.85$, $p = .037$, one tailed). In contrast, the control subjects showed the opposite pattern, with significantly higher ratings for doublet irregulars than doublet regulars (83 vs. 60; independent $t(30) = 5.04$, $p < 0.001$). JLU's ratings on irregulars were (non-significantly) lower than those of his controls (69 vs. 83; paired $t(15) = 1.18$, $p = .258$), whereas his ratings on regulars were significantly higher than those of his controls (94 vs. 60; paired $t(15) = 6.12$, $p < .0001$).

The three non-fluent aphasics showed a very different pattern. All three gave similar or lower ratings to doublet regulars than doublet irregulars (FCL: 64 vs. 70, independent $t(30) = 0.41$, $p = 0.687$; BMC: 0 vs. 50 for the two doublet regulars and two doublet irregulars to which he gave ratings; RBA: 94 vs. 83, independent $t(30) = 1.04$, $p = 0.306$).

JLU's pattern of lower ratings on doublet irregular than doublet regular past tense forms extended to novel verbs. The interaction between Aphasia/Control and Regularization/Irregularization of Novel Irregular Verb (e.g., *crived* vs. *crove*) was statistically significant ($F(1,34) = 15.67$, $p < .0005$, over items). JLU's ratings of irregularizations of novel irregulars (e.g., *crove*) were significantly lower than his ratings of regularizations of novel irregulars (*crived*) (39 vs. 94; paired $t(17) = 4.61$, $p < .0005$). In contrast, the control subjects gave irregularizations and regularizations of novel irregulars quite similar ratings (66 vs. 72; paired $t(17) = 1.69$, $p = .109$). JLU's ratings of irregularizations were lower than those of his controls (29 vs. 66; paired $t(17) = 2.42$, $p = .027$), whereas his ratings of regularizations were higher than those of his controls (94 vs. 72; paired $t(17) = 4.02$, $p < .001$).

Similarly, the interaction between Aphasia/Control and Novel Regular Past-Tense/Irregularization of Novel Irregular (e.g., *plagged* vs. *crove*) was statistically significant ($F(1,36) = 15.89$, $p < .0005$, over items). JLU's ratings of irregularizations (*crove*) were, on average, less than half as high as his ratings of novel regulars (*plagged*), which were uniformly given ratings of 100 (39 vs. 100; independent $t(36) = 5.46$, $p < .001$). The control subjects showed a much smaller difference (66 vs. 85; independent $t(36) = 9.87$, $p < .001$). Whereas JLU's ratings of irregularizations were lower than those of his controls (see previous paragraph), his ratings of novel regulars were higher than those of his controls (100 vs. 85, paired $t(17) = 25.59$, $p < .0001$).

Thus JLU gave high ratings to *–ed*-suffixed novel verbs, both to novel regulars (*plagged*), and regularizations of novel irregulars (*crived*). In fact, he gave ratings of 100 to all novel regular past tenses, and to 17 of the 18 regularizations of novel irregulars. This contrasts with the pattern shown by the three non-fluent aphasics. Two of them (BMC and RBA) could not rate novel verbs at all, and the third (FCL) gave them very low ratings. This contrast between fluent and non-fluent aphasia is expected. Given that novel verb forms could not be memorized, and therefore must be produced by a creative process, computation of *–ed*-suffixed novel forms should be highly impaired in non-fluent aphasia, but fully functional in fluent aphasia.

Despite his recognition of all irregular past tense forms, JLU accepted almost a quarter of the over-regularized forms (*digged*, *clinged*, and *bended*). His ratings of over-regularizations were borderline significantly greater than zero ($t(15) = 1.86$, $p = .083$, one-tailed). This is consistent with the predicted impairment of lexical memory and spared rule-processing.

JLU gave ratings of 0 to all 20 unmarked forms of regular verbs, and to all 20 unmarked forms of novel regular verbs. This contrasts with the performance of the three non-fluent aphasics, all of whom accepted at least some unmarked forms, and two of whom (BMC and RBA) gave ratings to unmarked forms which were significantly greater than zero. This contrast is consistent with the hypothesis that non-fluent aphasics have deficits involving morphological affixation and more general aspects of morphosyntactic processing, which are relatively spared in fluent aphasics.

Non-fluent vs. Fluent Aphasia

We directly compared the performance of the non-fluent and fluent aphasics with circumscribed lesions (that is, FCL vs. JLU). The interaction between Non-fluent/Fluent Aphasia and Regular/Irregular Past-Tense (e.g., *walked* vs. *dug*) was marginally significant ($F(1,34) = 2.99$, $p = .093$, over items), as was the interaction between Non-fluent/Fluent Aphasia and Doublet-Regular/Doublet-Irregular Past-Tense (e.g., *dived* vs. *dove*; $F(1,30) = 2.85$, $p = .102$). The ANOVA between Non-Fluent/Fluent Aphasia and Irregularization/Regularization of Novel Irregular (e.g., *crove* vs. *crived*) yielded a statistically significant interaction ($F(1,34) = 5.69$, $p = .023$), as did the ANOVA between Non-Fluent/Fluent Aphasia and Novel Regular Past-Tense/Irregularization of Novel Irregular (e.g., *plagged* vs. *crove*; $F(1,36) = 12.04$, $p = .001$). The interactions strengthen the hypothesis that, even in the receptive task of judgment, the computation of irregulars depends more upon left posterior regions, whereas the computation of *–ed*-suffixed forms depends more upon left anterior structures.

In the previous three sections, we presented an in-depth examination of the production (Study 1), reading (Study 2), and judgment (Study 3) of regular and irregular English past tense forms by agrammatic non-fluent aphasics with left frontal lesions and anomic fluent aphasics with left posterior lesions. We are aware of no other reports of the production or judgment of regular and irregular inflected forms by aphasic subjects, or of any investigations of the regular/irregular inflectional morphology distinction in fluent aphasia. However, there have been several studies of reading, writing and repetition of regular and irregular inflected forms given to patients with left frontal lesions. In each case the patient was less successful at reading, writing or repeating regular than irregular past tense or plural forms. We summarize these findings below, together with lesion and behavioral data from these patients.

Patients HT and VS.

Both patients suffered left middle cerebral artery strokes. CT scans revealed the following (Coltheart et al., 1980): In both patients, classical Broca's area was involved, although in VS the damage was probably partial, and the inferior pre-central involvement was minimal. In both patients there was damage to subcortical fronto-central white matter and insular cortical and subcortical areas. Both patients showed superior temporal sub-cortical damage, but only VS had superior temporal cortical damage. In both cases posterior aspects of the superior temporal gyrus were relatively spared, whereas the supramarginal gyrus was damaged; however, in HT only very anterior portions of the supramarginal gyrus were involved. VS had superior and middle parietal involvement, while HT did not.

Both HT and VS were “phonemic dyslexics,” having trouble using spelling-to-sound rules to pronounce novel words (Marin et al., 1976). Both subjects had non-fluent agrammatic speech: They both “produced short, halting phrases consisting almost entirely of concrete nouns and specific verbs. The function words of the language [were] used infrequently and inappropriately. Nouns [were] improperly inflected for number and were either uninflected or used in the progressive form” (Marin et al., 1976, p. 876). The two patients made similar errors in oral reading: They were impaired at reading function words (including pronouns, prepositions, articles, and conjunctions), had greater difficulty reading verbs than nouns, and made twice as many errors at reading *-ing*-forms in verbal than in nominal contexts (Marin et al., 1976). The patients also had difficulty in specifying number by means of plural inflection, and tended to read verbs in either the bare stem or the *-ing*-form. Both subjects had difficulty producing grammatical sentences, and were at chance at comprehending reversible passives, suggesting that they did not use the syntactic structure of the sentences to interpret their meanings (Schwartz et al., 1979).

Marin et al. (1976) investigated the inflectional morphology of HT and VS. They reported that “irregular plural nouns and verbs with irregular past tense forms are read several orders of magnitude better than their regular counter-parts” (p. 880), although it is not clear whether this pattern was observed in isolated word reading or in sentence reading. Moreover, these patients were successful at reading pluralia tantum nouns, which are likely to be stored in memory in their entirety (e.g., *trousers*, *clothes*), suggesting that the relative impairment of regulars is not attributable to an articulatory problem or to a failure to attend to the final /s/.

Patient JG and BM.

JG and BM both suffered left hemisphere strokes. JG had an infarction involving the left posterior frontal lobe, the insula and portions of the anterior inferior parietal lobe. BM's infarction was in the territory of the left middle cerebral artery, involving the posterior frontal and inferior parietal lobes, with little or no temporal lobe damage (Coslett, personal communication).

Coslett (1986) reports that although initially JG was aphasic, at the time of the language testing reported below his speech was not abnormal, as measured by the BDAE. However, he was a "phonological dyslexic" — that is, he had an impaired ability to "derive phonology from print non-lexically" (p. 1). He was also selectively impaired at reading function words, and omitted or substituted affixes when reading affixed words. As for BM, 10 years post-onset she was phonologically dyslexic, and on affixed words she made reading errors of affix omissions and substitutions (Coslett, 1986).

JG and BM were asked to read 47 regularly inflected and 47 irregularly inflected past tense and plural forms, matched on inflected-form frequency (Coslett, 1986). Both patients were statistically significantly less successful at reading regular than irregular forms. JG correctly read approximately 55% of the regular forms versus 83% of the irregulars forms ($\chi^2(1) = 7.18$ p =.007). BM correctly read approximately 19% of the regular forms versus 81% of the irregulars forms ($\chi^2(1) = 33.36$ p <.001).

Patient F38.

F38 suffered a closed head injury, which resulted in a left sub-dural hematoma and a fronto-parietal contusion (Coslett, 1988). She was reported to be phonologically dyslexic, and initially exhibited difficulty reading affixed words, as compared to unaffixed words. However, by the time of testing she had improved to the point of being no worse at reading affixed than unaffixed words (Coslett, 1988). She named 87% of the items in the Boston Naming Test (Goodglass et al., 1983), well within the normal range of age-similar control subjects.

F38 was given a writing-to-dictation task with the same 47 regular and 47 irregular past tense and plural forms given to JG and BM (Coslett, 1988). She successfully wrote only 51% of the regular forms, but 98% of the irregular forms ($\chi^2(1) = 24.68$ p <.001). This regular/irregular dissociation in writing is highly unlikely to be explained by an articulatory impairment. Her near-perfect performance at writing irregulars, in comparison to her severely impaired performance at writing regulars, suggests damage to neural structures subserving plural and past tense regular inflectional rules, with no role in writing irregulars. This contrast is particularly striking in light of her normal performance at the Boston Naming Test, as would be expected if, as predicted, irregulars are stored in lexical memory.

Patient SJD.

SJD suffered a stroke in the region of the left middle cerebral artery. A CT scan one month post-onset revealed a fronto-parietal enhancement, extending to the cerebral vertex (Badecker & Caramazza, 1991). Her speech was characterized by "occasional morphological and function word errors, ... and hesitations for word-retrieval. ... Preliminary studies of SJD's reading and writing abilities indicated that she produced morphological errors (affix omissions, substitutions and insertions). ... [In] a sentence generation task in which she was presented with a word (in written or spoken form) and asked to produce a spoken sentence containing the item, ... [a]n examination of the error corpus revealed ... a number of grammatical infelicities (function word omissions and substitutions, main verb omissions, selectional violations, and word order violations)" (Badecker & Caramazza, 1991, pp. 341-342). In a reading test, she read nouns and adjectives better than verbs or function words.

SJD was asked to read 50 irregular past tense forms and 50 regularly inflected verbs, matched on syllable length and surface frequency, as well as 50 uninflected verb forms, frequency-matched to the regular and irregular inflected forms (Badecker & Caramazza, 1991). She read the regulars less accurately than the irregulars (60% vs. 92% correct; $\chi^2(1) = 12.34$, p <.001) and the uninflected verbs (60% vs. 90%; $\chi^2(1) = 10.45$, p <.01). Moreover, she was significantly worse at reading regularly affixed verbs, nouns, and adjectives than their monomorphemic homophones (e.g., *links-lynx*, *frays-phrase*), matched on grammatical category, and balanced for letter-length and frequency (50% vs. 85% correct). Most of her errors at reading the affixed forms were morphological deletions (27% of items; e.g.,*bowled-bowl*) or substitutions (15% of items; e.g.,*bowled-bowling*), whereas most of her errors at reading the monomorphemic words were phonemic errors (15% of items; e.g., *bread-breast*). SJD was also asked to read 85 regularly suffixed words matched in surface frequency and letter length to 85 monomorphemic words containing initial letter sequences that are also words (e.g., *yearn, dogma*). She read correctly more monomorphemic embedded words than suffixed words (86% vs. 79%), although the difference was not statistically significant. For the suffixed words she produced primarily morphological deletions and substitutions (19% of items, 89% of errors), but she made fewer analogous errors for the embedded words (6% of items, 50% of errors): $\chi^2(1) = 3.76$, $p = .053$. Moreover, none of her errors on embedded word were deletions (e.g., *yearn-year*). These results indicate that the regularly affixed forms are difficult to read because of their morphological composition, and not because of a perceptual or attentional deficit leading to the reading of word-initial substrings. As with patient F38, SJD's near-perfect performance at reading irregular past tense forms is consistent with the existence of neural structures which subserve the reading of regular past tense forms, but are not necessary for the reading of irregular past tenses. This suggests that morphophonological and morphosyntactic computations may depend upon at least partially distinct cognitive and neural components. This view is strengthened by the finding that SJD was no worse at reading irregular than uninflected forms.

<u>Patient FM.</u>

FM suffered a stroke of the left middle cerebral artery. A CT scan two years post-onset showed a large area of lucency involving the posterior inferior frontal lobe, inferior parietal lobe, anterior temporal lobe, the underlying white matter, and the lateral basal ganglia (Badecker & Caramazza, 1987). The authors reported that FM's “speech is considered non-fluent with reduced phrase length, and his performance on sentence processing tasks such as sentence-picture matching reveals ‘asyntactic’ comprehension (i.e., he was significantly worse on matching thematically ‘reversible’ sentences like *the boy kissed the girl* than on ‘nonreversible’ sentences like *the boy threw the rock*). ... FM's reading performance includes ... [m]orphological errors (especially affix deletions and substitutions).” (pp. 282-283). In addition, he read nouns more reliably than adjectives than verbs, which were matched with each other on letter and syllable length and on frequency.

FM was asked four years post-onset to read 50 regularly inflected, 50 irregularly inflected, and 50 uninflected words, matched on letter length and surface frequency, and covering a wide frequency range (Badecker & Caramazza, 1987). The irregular forms were read with greater accuracy than the regular forms (34% vs. 10%; $\chi^2(1) = 7.05$, $p = .007$). In addition, the uninflected words were read more accurately than either the regular or irregular items. As a separate task, the same 150 words were read out loud, one word per trial, and FM was asked to repeat each word after counting to five. The irregularly inflected forms were repeated more successfully than the regularly inflected forms (74% vs. 56%, $\chi^2(1) = 2.81$, $p = .093$). The uninflected words were repeated with about the same success as the irregular forms (62% correct). FM's relative impairment at regulars in both the reading task and the listening and repetition task indicates that his deficit is not specific to either reading or listening. More recently, Badecker (1997) asked FM to read 40 regular and 40 irregular past tense forms item-matched on frequency, and these verbs’ stem forms. Irregular past tense forms were again read more accurately than regular past tense forms (25% vs. 10%). Past tenses of both verb types were read less accurately than their stem forms. FM was also asked to read 21 irregular past tense forms and 41 regular past tense forms. He read more irregular than regular past tense forms correctly (38% vs. 17%).

[Table 16 about here]

Summary.

All seven patients from previously reported studies (1) had left frontal lesions; (2) had greater deficits in producing and/or reading function words than content words (i.e., agrammatic speech and/or agrammatic reading), as well as other linguistic impairments associated with left anterior lesions, including difficulty understanding reversible passives or actives, phonological dyslexia, and greater deficits in producing or reading verbs than nouns; (3) and were worse at reading, writing or orally repeating regular than irregular past tense or plural forms. The evidence presented in these reports suggests that articulatory, frequency, letter length, and initial substring explanations could not account for this regular-irregular dissociation for one or more patients.

GENERAL DISCUSSION

Regular and Irregular Morphology

The results from the three studies reported here and from previous reports reveal double dissociations between regular and irregular inflectional morphology. Aphasics with non-fluent agrammatic speech or agrammatic reading were more impaired at producing, reading, judging, writing, or repeating regular than irregular past tense or plural forms. Aphasics with fluent speech with word-finding difficulty (anomia) were more impaired at producing, reading, and judging irregular than regular past tenses. The dissociations held even when a number of potential confounding factors were held constant between regular and irregular items: stem and past tense frequency; articulatory difficulty (phonological complexity) of the past tense items; number of letters in the past tense items; and consistency of spelling-to-sound mappings of past tense forms in reading tasks. Initial substring explanations also do not account for the data. Moreover, the agrammatic non-fluent aphasics in our studies produced virtually no over-regularizations, and had trouble producing and judging *–ed*-suffixed novel verb forms (e.g., *plagged, crived*). In contrast, the anomic fluent aphasics produced many over-regularizations and were able to produce and recognize *–ed*-suffixed novel verb forms, but had difficulty producing and recognizing novel irregularizations (e.g., *crive-crove*).

The contrasting regular/irregular patterns were consistent and reliable. Of the agrammatic non-fluent aphasics examined in our studies, both patients who performed the production task showed the deficit of regulars vs. irregulars, seven of nine showed it in the reading task, and all three showed it in the judgment task, as measured by the percentage of correctly produced or read forms, acceptability ratings, or reaction times. These differences were statistically significant or approaching statistical significance for both patients in the production task, six of the seven patients in the reading task, and two of the three patients in the judgment task. The only two patients who did not show a relative deficit of regulars, in the past tense reading task, showed a very small and highly non-significant advantage at reading irregulars over regulars (in both cases, 29% vs. 24%, $p > .7$). All seven of the aphasics in the previously reported studies showed the pattern, with the difference reaching statistical significance in all cases.

Of the anomic fluent aphasics examined in our studies, all six patients examined in the production task showed the predicted relative deficit of irregulars, as did four of the five patients in the reading task, and the only fluent aphasic examined in the judgment task, on doublet verbs. These differences were significant or approaching significance for three of the six patients in the production task, three of the four in the reading task, with spelling-to-sound consistency held constant, and for the one patient examined in the judgment task.

The only patient who did not show a relative deficit of irregulars, in the past tense reading task, had equal difficulty with regular and irregular items, with spelling-to-sound consistency held constant (22% vs. 22%).

These data are not consistent with any previously reported single-system connectionist models. To our knowledge, only one connectionist model has attempted to simulate double dissociations between regular and irregular morphological forms (Joanisse & Seidenberg, 1998; Joanisse & Seidenberg, 1999). Like models of reading aloud (Plaut et al., 1996; Plaut & Shallice, 1993; Seidenberg & McClelland, 1989), this model has distinct representations for semantics and phonology. Simulations of damage to the phonological representation led to worse performance producing past tenses of novel than of regular and irregular verbs, but *no reliable difference* between regulars and irregulars. Simulations of damage to the semantic representation led to worse performance producing past tenses of irregulars than of regulars and novel verbs. Thus lesions to the model yielded double dissociations between irregulars and novel verbs, but, crucially, *not* between irregulars and regulars, even from phonological lesions. In the initial report (Joanisse & Seidenberg, 1998), phonological lesions led to *better* performance on regulars than irregulars. In the second report (Joanisse & Seidenberg, 1999), regulars again had the advantage when regulars and irregulars were matched on past tense frequency. Even when regulars had lower past tense frequencies than irregulars, there were not significantly more errors on regulars. Only when the authors examined a subset of the most severely lesioned models could they find some simulations which yielded reliably worse performance at regulars than irregulars. Thus the data presented in the present report as well as in previous reports, of worse performance at regulars than irregulars, by a large number of patients over five tasks (production, reading, judgment, writing, and repetition), is not consistent with the sole previously reported connectionist model attempting to simulate double dissociations between regular and irregular morphology.

Rather, the regular/irregular double dissociations between the non-fluent and fluent aphasics suggest that the computation of each of the two types of inflected forms depends upon distinct neural underpinnings. This claim is strengthened by the finding that each dissociation held even in cases of circumscribed anterior or posterior lesions, and was consistently associated with a particular cluster of other behavioral impairments. Unlike double dissociations between small numbers of patients who are not clearly differentiated in circumscribed lesion site or in associated behavioral impairments (e.g., Marslen-Wilson & Tyler, 1997), it cannot be claimed that the dissociations reported here are flukes due to individual subject variation, perhaps as a consequence of post-lesion recovery.

The data also support the hypothesis that one system subserves at least certain aspects of the mental grammar, in both syntax and affixal morphology, whereas another subserves the mental lexicon, encompassing irregular forms as well as uninflected content words. This hypothesis is supported by the co-occurrence of impairments of regular morphology and syntax among the agrammatic non-fluent aphasics, and the co-occurrence of impairments of irregular morphology and lexical memory among the anomic fluent aphasics.

The non-fluent aphasics had difficulty with aspects of syntax as well as regular past tense forms. First, all had agrammatic speech, as defined by a reduction of phrase length and grammatical complexity. In addition, all the non-fluent aphasics tested on syntactic comprehension tasks were impaired on these tasks, indicating that these patients suffered from receptive agrammatism as well. Finally, the non-fluent aphasics showed evidence of syntactic deficits affecting the computation of inflection, independent of the regular/irregular distinction, in the production, reading, and judgment tasks.

In contrast, the fluent aphasics showed independent impairments of lexical memory. All 9 patients had word-finding difficulties (anomia), in spontaneous speech and/or in picture naming. In addition, in both the production and reading tasks, the fluent (but not non-fluent) aphasics produced more distortions on irregular than regular verbs. This suggests that the fluent (but not non-fluent) aphasics suffered damage to brain structures which subserve the sound patterns of stored words, and that the computation of irregulars but not regulars is particularly dependent upon these structures.

Morphological Theory

The data presented in this report are relevant to morphological theory. Some theories of morphology posit that irregulars as well as regulars undergo affixation, either with phonologically overt morphemes, for irregulars as well as regulars (e.g., *keep* → *kep* + /-t/), or with "zero-morphemes", for many irregulars (e.g., *hit* → *hit* + ∅; *dig* → *dug* + ∅) (Halle & Marantz, 1993). On this view, if affixation were impaired in agrammatic non-fluent aphasia, it should affect irregulars as well as regulars. In particular, it should result in the omission not only of the regular affix, but also of irregular affixes. Although omission of the zero morpheme would lead to the production of surface forms that are phonologically indistinguishable from the correct (zero-affixed) form (e.g., *dug*), irregulars like *keep* should be produced as *kep*. However, none of the non-fluent aphasics produced any such forms, for either real irregulars or novel irregulars, in either the past tense production or reading tasks — despite the fact that we paid special attention to the omission of final consonants, and that there were 11 such verbs in the production task (the irregulars *keep-kept, bend-bent, make-made, stand-stood, send-sent,* and *think-thought*, and the novel verbs *treave-treft, sheel-shelt, cleep-clept, shreep-shrept,* and *prend-prent*), and 9 such verbs in the reading task (*sweep-swept, flee-fled, buy-bought, keep-kept, leave-left, feel-felt, lend-lent, spend-spent,* and *send-sent*). Moreover, it is not that aphasics simply do not produce such forms, since one of the *fluent* aphasics produced three of them (patient HFL: *think-/__/, keep-kep,* and *shreep-shrep*) — although it is intriguing that HFL made some errors similar to those of non-fluent aphasics, and was the only fluent aphasic to have caudate nucleus damage. Importantly, the non-fluent aphasics actually produced four analogous forms (patient KCL: *lend-len, send-sen, spend-spen*; NSL: *lend-len*), but on the *stem* reading task, where the errors could not have been produced as a result of affix omission. These results pose a challenge for the view that irregulars undergo morphonological affixation.

Localization

All eleven of the non-fluent aphasics that we tested had damage to left frontal regions (see Table 17). This was the only region damaged in all eleven patients. In all cases where the lesion location was reported more precisely, Broca's area was reported as damaged. At least six of the patients had lesions involving the basal ganglia, including the putamen in all detailed lesion reports. However, one non-fluent aphasic did not have any apparent basal ganglia damage. Insular structures were damaged in at least five patients, and spared in at least two. At least seven patients had inferior parietal damage, which was limited to the anterior supramarginal gyrus in all detailed reports. However, parietal structures did not appear to be affected in four patients. At least six of the patients had some temporal lobe damage, whereas the brain scans of two patients indicated sparing of all temporal-lobe structures.

[Table 17 about here]

As discussed above, all of the non-fluent aphasics showed the expected pattern of worse performance at regulars than irregulars, other than two subjects, who did not show any difference between the two verb types. The lack of a relative impairment of regulars for these two subjects can be attributed to extensions of their lesions to temporal and parietal structures, which would be expected to impair irregulars. Because the only brain structure known to be damaged in all eleven subjects was left frontal cortex, this region is implicated in morphological affixation. This is consistent with a dual-system view. Moreover, one of the patients (RBA), had frontal damage apparently limited to Broca's area, suggesting that Broca's area and/or nearby frontal structures may be necessary for certain aspects of grammar, in particular for affixation, in both expressive (production) and receptive (jusgment) tasks. More generally, the implication of these frontal regions is consistent with the hypothesis that a "procedural" system, rooted in frontal/basal-ganglia structures and previously implicated in motor and cognitive skills and habits, plays a role in the mental grammar (Ullman et al., 1997b).

The seven fluent aphasics with reported anatomical lesion information all had temporal and/or inferior parietal (i.e., temporo-parietal) lesions (see Table 17). Six of them had temporal lobe damage, in a variety of regions. Five of them had inferior parietal damage. Three patients had both insular and basal ganglia damage. Only two had any known damage, in both cases minimal, to the frontal lobe.

As discussed above, all nine of the fluent aphasics showed the expected pattern of worse performance at irregulars than regulars, other than one subject, who did not show any difference between the two verb types. No brain scan was available for this individual. Thus the only brain region whose damage was consistently associated with impaired irregular morphology was the broad temporal/temporo-parietal region, as predicted by a dual-system view. The pattern of distortion errors on irregulars suggests that one function of this region involves the stored sound patterns of irregular past tense forms, and presumably other lexical items as well. This is consistent with Wernicke's claim that the posterior portion of the left superior temporal gyrus is the center for "sound images" of words (Wernicke, 1874), although our data do not implicate this particular region. The findings are also consistent with the view that a "declarative" memory system, rooted in temporal/temporo-parietal structures and previously implicated in the memory for conceptual knowledge, also subserves lexical memory, including the stored sound structures of words (see Ullman et al., 1997b).

None of the fluent aphasics were known to have severe damage to the left frontal lobe: Of the seven patients with lesion reports, the left frontal lobe was spared in five, and was minimally damaged in two. Thus the relative sparing of affixation was always accompanied by spared or largely spared left frontal regions. In contrast, as discussed above, the non-fluent aphasics showed a consistent association between left frontal damage and certain types of grammatical impairment. This greatly strengthens the view that left frontal structures play an important role in aspects of the mental grammar, particularly in morphological affixation.

These conclusions do not address or preclude the possibility that structures other than those examined may play an important role in the mental grammar or the mental lexicon. Nor do they obviate the possibility that temporal-lobe regions may subserve grammatical functions other than morphological affixation and the syntactic licensing of inflection. Finally, they do not preclude the claim that left frontal structures also play some sort of role in the search, selection or retrieval of lexical and semantic information (see Buckner & Tulving, 1995). These are open questions which must be further investigated.

SUMMARY AND CONCLUSION

Eighteen aphasics with non-fluent agrammatic speech or with agrammatic reading were presented or reviewed in this report. Sixteen of the 18 showed a pattern of worse performance at computing regular than irregular past tense or plural forms, in production, reading, judgment, writing, or repetition tasks. The other two aphasics showed no difference in their computation of regular and irregular forms. Nine aphasics with fluent speech and anomia were presented in this report. Eight of the 9 showed a pattern of worse performance at computing irregular than regular past tense forms, in production, reading, and judgment tasks. The remaining fluent aphasic showed no difference in the computation of regular and irregular forms. These double dissociations were maintained even when a variety of other factors, including frequency and articulatory difficulty, were controlled for. The agrammatic non-fluent aphasics also had particular trouble computing over-regularizations and novel *–ed*-suffixed verbs. The anomic fluent aphasics had little trouble computing over-regularizations and novel *–ed*-suffixed forms, but were impaired at novel irregularizations (e.g., *crive-crove*).

These findings are not consistent with any previously reported connectionist models of regular and irregular morphology, including models with distinct representations for semantics and phonology (Joanisse & Seidenberg, 1999). The results support a dual-system model in which the computation of regular and irregular inflected forms depend upon distinct neural underpinnings. The association of agrammatic non-fluent aphasia, left anterior lesions, the apparent syntactic deficits in the three inflection tasks, and impairments of morphological affixation, suggests that morphological affixation and at least some syntactic processes are subserved by left anterior structures. An examination of the tested aphasics' lesioned structures suggests that left frontal regions, particularly Broca's area and adjacent frontal structures, play a particular important role in these grammatical functions. The association of anomic fluent aphasia, left posterior lesions, lexical difficulties, and impairments of irregular morphology, including a large number of distortions on irregular verbs, suggests that left posterior brain regions subserve a lexical memory that includes the sound patterns of stored forms, and encompasses irregularly inflected as well as uninflected words. An examination of the tested aphasics' lesioned structures implicates left temporal and/or temporo-parietal structures in these functions.

In conclusion, we have presented a detailed analysis and discussion of the computation of regular and irregular inflected forms in agrammatic non-fluent aphasia and anomic fluent aphasia. The findings support the view that language is a modular system — that at least certain aspects of the mental grammar, including at least certain syntactic computations as well as morphological affixation, are subserved by left frontal structures, whereas the stored words of lexical memory, including irregularly inflected forms, depend on left temporal/temporo-parietal regions. The results are consistent with the view that aspects of the mental grammar are subserved by a frontal/basal-ganglia "procedural memory" system that also underlies cognitive and motor skills, whereas the mental lexicon is subserved by a temporal/temporo-parietal "declarative memory" system that also underlies factual knowledge about the world (see Ullman et al., 1997b).

APPENDIX

Here we present detailed behavioral and lesion data for the non-fluent and fluent aphasics whose performance is discussed in studies 1 through 3.

Non-fluent Aphasic Subjects

FCL suffered a left hemisphere stroke in 1973, 19 years prior to testing. An MRI scan 19 years after the onset of his stroke revealed a large left dorsolateral frontal lobe lesion involving almost all of the inferior and middle frontal gyri, including all of Broca's area and its underlying white matter, as well as the entire insula. In the basal ganglia, the entire lenticular nucleus (putamen and globus pallidus) was involved, while the caudate nucleus was spared. A superior extension of the lesion included the lower two-thirds of the premotor, motor, and somatosensory cortices, and underlying white matter and periventricular white matter. The temporal lobe and remaining parietal lobe were spared. FCL was classified as a Broca's aphasic on the basis of clinical consensus and the BDAE. Independent studies showed that he was impaired at using the syntactic structure of sentences to comprehend their meanings (Hickok & Avrutin, 1995; Hickok & Avrutin, 1996; Sherman & Schweickert, 1989) or to judge their grammaticality (Grodzinsky & Finkel, 1998). He correctly named 75% of the items on the Boston Naming Test (Goodglass et al., 1983).

RBA suffered a left hemisphere stroke 9 years before testing. A CT scan showed that the resulting lesion involved Broca's area, with deep extension involving the subcallosal fasciculus at the lateral angle of the left frontal horn. There was a patchy posterior extension across the left temporal isthmus and a superior extension to the premotor, motor and sensory cortices. He was diagnosed as a Broca's aphasic on the basis of clinical consensus and the BDAE. His BDAE grammatical form score 2 years after onset was 1 out of 7, indicating no variety of grammatical constructions in his speech. His BDAE word finding score was 7, indicating that his speech contained only content words, with a complete lack of function words.

CIG suffered a left hemisphere stroke in 1983, 12 years prior to testing. CT and MRI scans carried out 0.5 and 12 years post-onset, respectively, showed a large posterior frontal lobe infarction involving Broca's area and surrounding structures, the insula, and part of the putamen. There was also a superior extension involving most of the motor and sensory cortex, and a small portion of the anterior supramarginal gyrus. The temporal lobe and remaining temporo-parietal areas were spared, as were the caudate nucleus and globus pallidus. She was classified as a Broca's aphasic on the basis of the WAB.

WRO suffered a left hemisphere stroke in 1988, 7 years prior to testing. A CT scan performed one year post-onset revealed a large posterior frontal lesion involving Broca's area and surrounding structures, including the insula, claustrum and putamen, and the anterior segment of the superior temporal gyrus. The thalamus, parietal lobe and remaining temporal lobe were spared. He was classified as a Broca's aphasic on the basis of clinical assessment and the WAB.

LDO suffered a left hemisphere stroke in 1977, 15 years prior to testing. A CT scan revealed a left fronto-parietal lesion, including most of Broca's area, with deep extension to the border of the frontal horn (thereby also including the medial subcallosal fasciculus), and to the insular structures, the putamen and globus pallidus, the head of the caudate, and the anterior limb of the internal capsule. There was also an extension to the temporal isthmus and Wernicke's area, the lowest 2/5ths of the motor and sensory cortices, and anterior supramarginal gyrus. He was classified as a Broca's aphasic both on the basis of clinical consensus and the BDAE. Previous studies showed that he was impaired at using the syntactic structure of sentences to comprehend their meanings (Grodzinsky, 1989; Sherman & Schweickert, 1989).

PJ suffered a left hemisphere stroke in 1979, 11 years prior to testing. Stark, Cosslet, and Saffran (1992) report that PJ had suffered an "extensive infarction involving left frontal, and, to a lesser extent, parietal and superior temporal lobes." Saffran (personal communication) identified PJ as a "non-fluent aphasic." Schwartz et al. (1987) classified her as "agrammatic."

KCL suffered a left hemisphere stroke in 1986, 8 years before testing. His CT scan showed a large low density area in frontoparietal cortex and in the basal ganglia region and deep white matter. He was diagnosed as a Broca's aphasic on the basis of clinical consensus and the BDAE.

NSL suffered a left hemisphere stroke in 1984, 11 years before testing. His CT scan showed a large left frontoparietal infarction. He was diagnosed as a Broca's aphasic on the basis of clinical consensus and the BDAE.

HTA suffered a left hemisphere stroke in 1992, 5 years before testing. Her CT scan showed involvement of the left posterior frontal lobe, the basal ganglia and periventricular white matter. The infarct extended to the cortical surface of frontal lobe and the anterior portion of the temporal lobe, with a sparing of posterior temporal regions, including Wernicke's area. She was diagnosed as a Broca's aphasic on the basis of clinical consensus and the BDAE.

NWH suffered a left hemisphere stroke in 1994, 3 years prior to testing. His MRI scan showed involvement of a large area of the left frontal and parietal lobes in the perisylvian region and in posterior parietal areas. He was diagnosed as a Broca's aphasic on the basis of clinical consensus and the BDAE.

BMC suffered a left hemisphere stroke more than one year before testing. A CT scan 6 months after onset showed that the lesion included all of Broca's area, with a patchy subcortical extension toward the frontal horn involving less than half of the medial subcallosal fasciculus. There was extensive involvement of the internal capsule, globus pallidus, putamen, and insular structures. A superior extension included the motor and sensory cortices for the mouth. A patchy lesion was present in the anterior supramarginal gyrus, and, subcortically, in the posterior third, of the periventricular white matter, possibly interrupting the auditory contralateral pathways. In the temporal lobe the lesion included the amygdala and extended upward to involve almost all of Wernicke's area, the areas anterior and inferior to it, and the subcortical temporal isthmus. He was diagnosed as a Broca's aphasic on the basis of the BDAE.

Fluent Aphasic Subjects

JLU suffered a left hemisphere stroke in 1992, nine months before testing. An MRI scan carried out 11 months post-onset revealed a left posterior lesion. In the temporal lobe there was a patchy lesion involving less than half of Wernicke's area. The lesion continued up into the inferior parietal lobe and included the posterior supramarginal gyrus area and the angular gyrus. The lesion also extended posteriorly, involving a small portion of the lateral occipital gyrus (Brodmann's area 19). The frontal lobe and basal ganglia were spared, as were medial temporal lobe structures, including the hippocampus, parahippocampal gyrus, and entorhinal cortex. He correctly named 48% of the items in the Boston Naming Test (Goodglass et al., 1983) six months post-onset, and 58% (40% , according to a first-response criterion) at the time of the language testing reported in this paper. In contrast, his spontaneous speech at the time of language testing was quite fluent and grammatical. His speech was assigned a WAB fluency and grammaticality score of 8.5/10 (fluent speech, with mostly complete, relevant sentences, though slightly circumlocutory, with some word-finding difficulty), and a BDAE grammatical form score of 5.5/7 (a variety of grammatical constructs, with some word-finding difficulty). No articulatory problems were observed, either in his spontaneous speech, or in his responses in the language tasks. Six months after onset, his comprehension of auditory commands was spared, with 15/16 points on the BDAE commands.

HFL suffered a left hemisphere stroke in 1988, 7 years before testing. An MRI scan performed one year post-onset revealed a lesion involving the head of the caudate nucleus, putamen, and globus pallidus, the insula, deep white matter pathways, and the temporal isthmus. Thalamic nuclei were largely spared. He had fluent speech (8/10 by the WAB), and was classified as an anomic aphasic on the basis of clinical consensus and the WAB.

JHA suffered a left-hemisphere CVA in 1988, 6 years before testing. A CT scan taken 3 years post-onset revealed a left occipito-parietal lesion. The lesion included a portion of the supramarginal gyrus and most of the angular gyrus and the white matter deep to these areas. A superior extension of the lesion involved most of the left superior parietal lobule, and a posterior extension involved a portion of the left occipital lobe. A small area of low density was present in the middle frontal gyrus and the white matter deep to it. He was classified as an anomic aphasic on the basis of the BDAE.

JMO suffered a left hemisphere stroke in 1977, 17 years prior to testing. A CT scan taken 14 years post-onset showed a large left temporal lobe lesion. The superior, middle and inferior temporal gyri and the white matter deep to them were involved, as were Wernicke's area and the anterior and posterior temporal isthmus. The temporal isthmus lesion interrupted the contralateral fibers of both the auditory and optic pathways. The lesion also extended into Brodmann’s area 37 of the temporal lobe. Portions of the amygdala and hippocampus were involved. The lesion also involved most of the putamen and part of the insula. A superior extension included the supramarginal gyrus, the angular gyrus, and the white matter deep to these areas, as well as the superior parietal lobule. A posterior extension involved Brodmann’s areas 18 and 19 of the occipital lobe. His frontal lobes were spared. He was classified as an anomic aphasic on the basis of the BDAE.

WBO had a left-hemisphere aneurysm which was resected in 1991, 3 years before testing. The resulting lesion involved the left anterior temporal pole, and extended superiorly into the frontal lobe just medial to the inferior border of the insular cortex. The putamen, caudate nucleus, thalamus, and insular cortex were spared. He had fluent speech with word retrieval problems and semantic paraphasias.

APE suffered 2 strokes, in 1982 and in 1992. The second one was 4 years before testing. Her scan revealed that she had patchy left temporo-parietal lesion involving the supramarginal gyrus, portions of the angular gyrus, the white matter deep to them, the superior, middle and inferior temporal gyri, the white matter deep to them, posterior portions of insular structures, the putamen and the globus pallidus. The frontal lobes were spared. Her spontaneous speech was characterized by word-finding difficulties and phonological and semantic paraphasias.

LBR suffered a left middle cerebral artery infarct in 1993, 2 years prior to testing. His CT scan 3 months post-onset revealed involvement of the left temporal lobe, with extensions into the parietal and occipital lobes. He was diagnosed as a Wernicke’s aphasic on the basis of clinical consensus and the BDAE, and had word-finding impairments, as revealed by the Boston Naming Test (Goodglass et al., 1983).

RHH suffered a left hemisphere stroke in 1993, 3 years prior to testing. An acute report from a CT scan obtained the day he was admitted to the hospital showed no evidence of lesion or hematoma. He was diagnosed as a Wernicke's aphasic on the basis of clinical consensus and the BDAE, and had word-finding impairments, as revealed by the Boston Naming Test.

YHY suffered a left hemisphere stroke in 1992, 3 years prior to testing. No MR or CT scans were available. Medical reports and speech and language progress reports all indicate fluent aphasia. She was diagnosed as a Wernicke's aphasic on the basis of clinical consensus and the BDAE, and had word-finding impairments, as revealed by the Boston Naming Test.

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NOTES

[1] A note on terminology is in order before we proceed. A distinction must be made between the notion of a "mental lexicon," which we refer to as a storage place (whether it involves simple rote lists of forms or distributed representations in an associative memory), and the way the term "lexicon" is often used in linguistic theories. Most such theories assume an organization in which syntactic computations draw words from the lexicon (Anderson, 1992; Chomsky, 1965; Chomsky, 1970; Halle & Marantz, 1993; Jackendoff, 1997; Lieber, 1992; Sciullo & Williams, 1987). However, the nature of the "linguistic" lexicon itself is controversial, as to whether it is a simple storage place (the mental lexicon) or whether, *in addition*, rule-based computations are carried out there (Anderson, 1992; Chomsky, 1970; Halle & Marantz, 1993; Lieber, 1992; Sciullo & Williams, 1987; Spencer, 1991). In this paper we focus on the mental lexicon, and do not take a strong position on the nature of the linguistic lexicon.

[2] As we discussed in Note 1, some linguistic theories assume that rule-based computations are carried out internally to the "linguistic" lexicon, even for inflectional morphological transformations such as past tense computation. According to such theories, both regular and irregular past tense verbs are formed in and may be stored in the linguistic lexicon, and are taken from there for further syntactic composition already inflected. According to the dual-system view which we will be testing in this paper, the use of irregulars depends upon the mental lexicon, whereas the use of regulars depends upon rule-based operations, irrespective of the extent to which the linguistic lexicon and/or syntax subserve derivational and/or inflectional morphology.

[3] We use the term "anomic fluent aphasic" to refer to fluent aphasics who have word-finding difficulties — that is, who are anomic. We do *not* use the term to refer to aphasics with the aphasic classification of "anomic aphasia."

LIST OF FIGURES

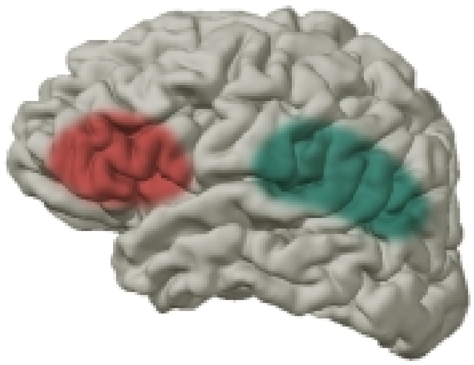
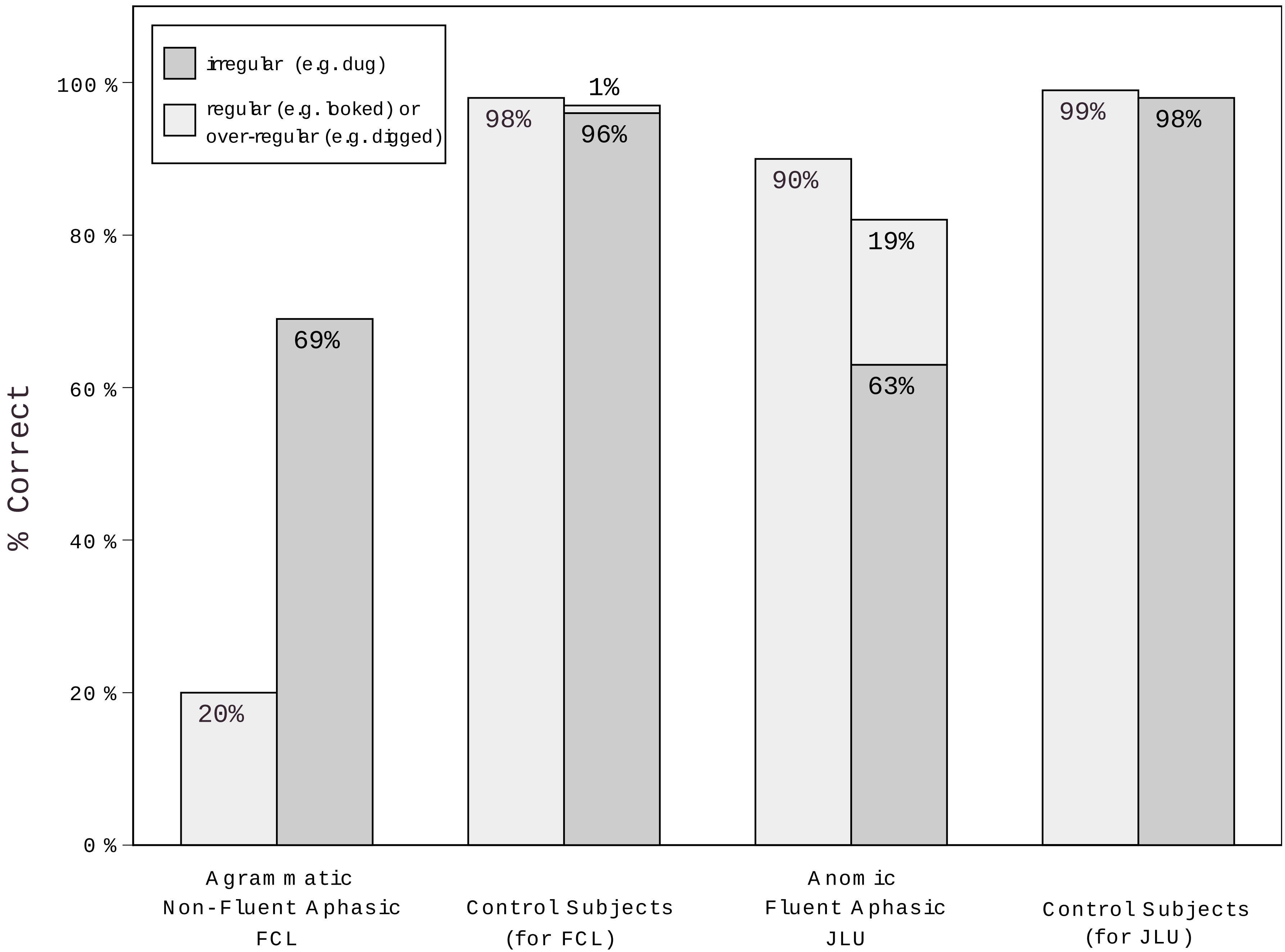


Figure1.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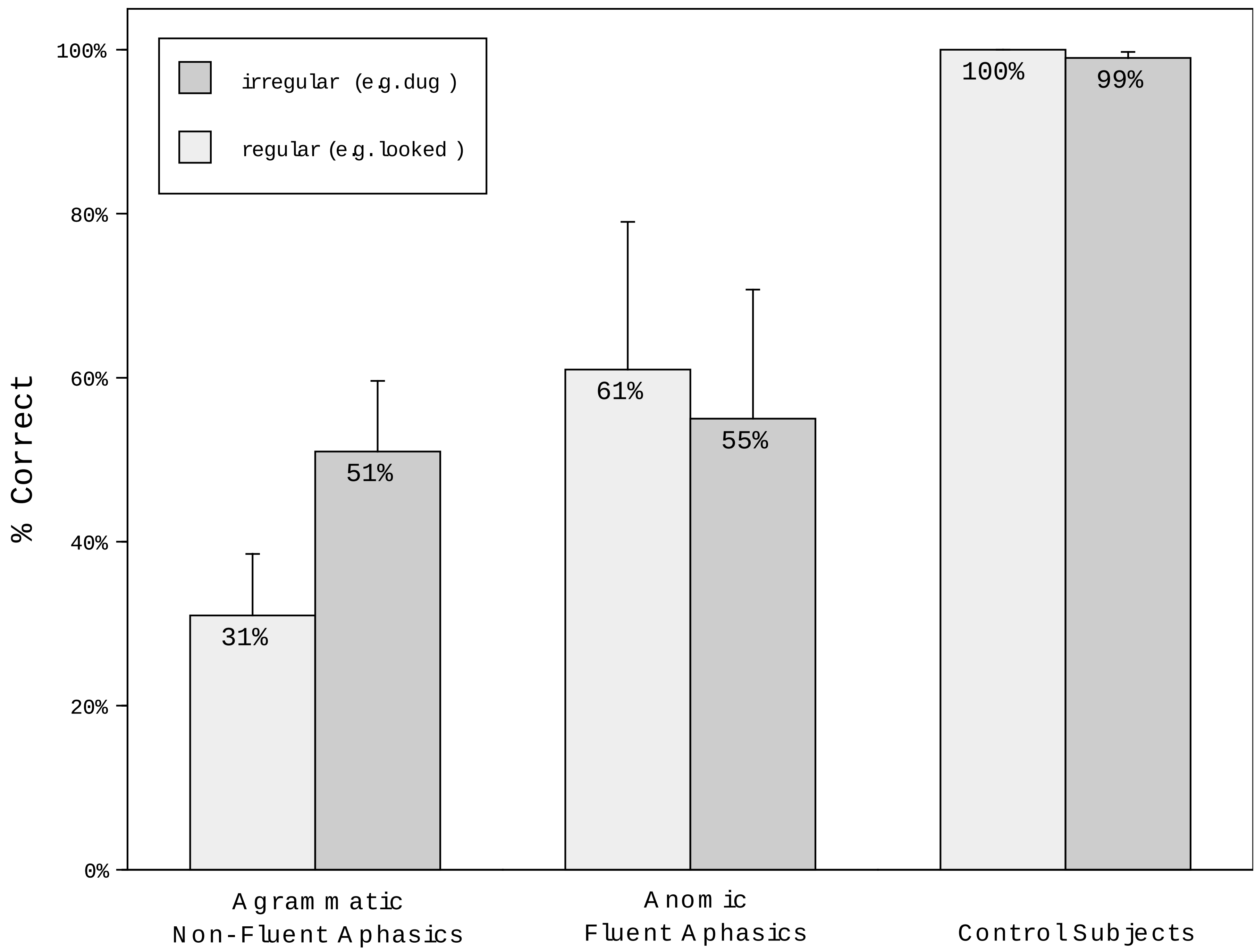

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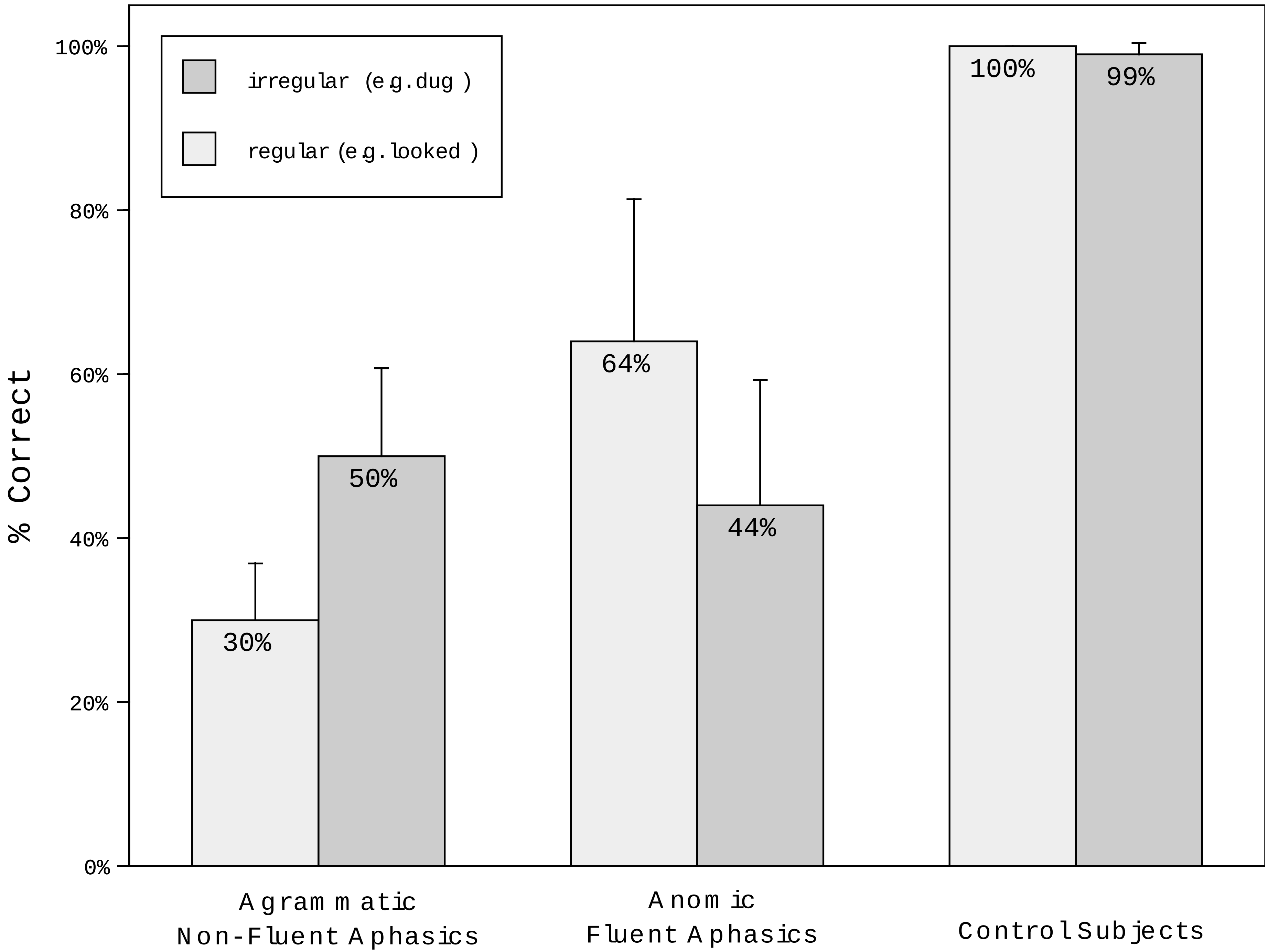
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Agrammatic
Non-Fluent Aphasics
Anomic
Fluent Aphasics
Control Subjects

TABLES

Subject	**Date of Birth**	**Sex**	**Age**	**Native English**	**Years of Education**	**Former Occupation**	**Other Information**	**Pre-Morbid Handedness**	**Current Handedness**
Non-Fluent Aphasics									
FCL	11/26/32	M	59	Y	16	engineer	smoker	R	R
RBA	12/19/29	M	65	Y	16	product management		R	R
CIG	12/07/22	F	72	Y	18	teacher	-	R	R
WRO	02/27/43	M	52	Y	14	maitre d'	-	R	A
LDO	02/06/27	M	65	Y	18	-	-	R	-
PJ	09/29/37	F	51	Y	12	hairdresser	-	R	R
KCL	07/07/36	M	60	Y	18	economist	-	R	R
NSL	08/20/24	M	72	Y	10	in the Navy	smoker; drinker	R	L
HTA	02/02/57	F	39	Y	12	in sales	-	R	L
NWH	04/19/28	M	68	Y	14	in sales	drinker; heavy smoker	R	L
BMC	07/24/50	M	44	Y	14	carpenter	drinker; heavy smoker	R	R
Fluent Aphasics									
JLU	09/18/43	M	49	Y	12	plant manager	smoker	R	R
HFL	03/14/42	M	53	Y	18	engineer	-	R	R
JHA	12/15/33	M	60	Y	12	-	heart attack	R	L
JMO	09/24/29	M	64	Y	20	parking lot attendant	knife wound	R	R
WBO	12/24/38	M	55	Y	6	-	aneurysm	R	R
APE	05/10/47	F	48	Y	14	-	-	R	-
LBR	05/18/38	M	58	Y	18	Army pilot	heart attack	R	R
RHH	11/28/29	M	67	Y	12	in advertising	car accident	R	R
YHY	10/29/31	F	65	Y	13	court reporter	drinker; angioplasty	R	R

Table 1

Aphasic Subjects: Summary of Demographic Data.

Note: Age is calculated at the date of past tense testing. A dash (-) indicates no information is available.

Subject	Date of Lesion Onset	Cause of Lesion	Testing Date	Years from Onset to Testing	Past Tense Tests	Hemiparesis	Aphasia Classification
Non-Fluent Aphasics							
FCL	10/12/73	stroke	07/92	19	prod, read, judg	R weakness	Broca's
RBA	04/85	stroke	08/18/94	9	prod, judg	R weakness	Broca's
CIG	04/83	stroke	03/29/95	12	read	-	Broca's
WRO	02/88	stroke	03/30/95	7	read	-	Broca's
LDO	1977	stroke	1992	15	read	R weakness	Broca's
PJ	12/79	stroke	10/92	13	read	R weakness	-
KCL	10/16/87	stroke	07/10/95	8	read	R weakness	Broca's
NSL	08/29/84	stroke	07/12/95	11	read	R weakness	Broca's
HTA	02/10/92	stroke	09/10/96	5	read	R weakness	Broca's
NWH	01/03/94	stroke	02/01/97	3	read	R weakness	Broca's
BMC	04/22/93	stroke	08/08/94	1	judg	R weakness	Broca's
Fluent Aphasics							
JLU	08/08/92	stroke	05/23/93	1	prod, judg	-	-
HFL	05/88	stroke	03/29/95	7	prod, read	-	Anomic
JHA	11/88	stroke	08/29/94	6	prod	-	Anomic
JMO	1977	stroke	08/11/94	17	prod	-	Anomic
WBO	04/10/91	resection	06/29/94	3	prod	-	-
APE	1982;1992	strokes	01/26/96	14, 4	prod, read	-	-
LBR	10/28/93	stroke	10/20/95	2	read	none	Wernicke's
RHH	08/22/93	stroke	09/10/96	3	read	none	Wernicke's
YHY	10/92	stroke	10/27/95	3	read	none	Wernicke's

Table 2

Aphasic Subjects: Clinical and Behavioral Summary.

Note. Only past tense tests that were successfully carried out are indicated. prod = past tense production task;

read = past tense reading task; judg = past tense judgment task.

	Verb Stem	Stem Freq. FK	Stem Freq. AP	Past Tense Form	Past Tense Freq. FK	Past Tense Freq. AP	Verb Complement/ Adjunct
				Regular Verbs			
	scowl	0.00	0.00	scowled	1.61	0.00	at Joe
	tug	0.69	2.64	tugged	1.10	1.79	at it
	flush	0.69	3.71	flushed	0.69	1.79	a toilet
	cram	0.00	3.37	crammed	0.00	1.95	it in
	mar	1.10	3.04	marred	0.00	3.30	its beauty
	chop	0.69	3.30	chopped	0.69	3.14	an onion
	flap	0.00	2.30	flapped	1.61	2.08	one wing
	stalk	0.00	1.95	stalked	1.95	3.30	a deer
	cook	2.71	4.48	cooked	1.10	3.64	a fish
	scour	0.69	2.64	scoured	0.00	3.33	a pot
	slam	0.00	3.66	slammed	2.64	5.65	a door
	cross	3.26	6.22	crossed	3.30	6.20	Elm Street
	rush	1.39	5.06	rushed	3.04	6.21	after Albert
	shrug	0.00	3.30	shrugged	2.94	4.96	one shoulder
	rob	1.10	4.83	robbed	1.10	4.80	a bank
	drop	3.56	7.36	dropped	4.34	8.14	another glass
	look	5.71	8.35	looked	5.79	7.64	at Susan
	walk	4.20	6.88	walked	4.97	7.36	along there
	stir	2.08	5.14	stirred	2.08	4.61	it up
	soar	0.00	4.51	soared	1.39	6.09	over water
Mean		*1.4*	*4.1*		*2.0*	*4.3*	
SD		*1.7*	*2.0*		*1.6*	*2.2*	
Range		*0.0 - 5.7*	*0.0 - 8.4*		*0.0 - 5.8*	*0.0 - 8.1*	
				Irregular Verbs			
	swim	2.40	5.24	swam	1.95	5.02	a mile
	dig	2.30	5.38	dug	2.08	4.69	a hole
	swing	2.48	4.68	swung	3.78	4.39	a bat
	cling	1.95	4.01	clung	2.64	4.01	onto her
	wring	1.10	2.89	wrung	0.00	0.00	a towel
	bend	2.56	4.34	bent	2.71	3.99	a spoon
	bite	2.08	4.51	bit	2.08	4.22	into it
	feed	3.83	6.35	fed	2.20	4.47	our cat
	come	6.07	8.91	came	6.43	9.52	into town
	make	6.67	9.94	made	6.15	9.37	a mess
	give	5.96	9.23	gave	5.66	9.00	a donation
	think	6.07	9.84	thought	5.83	8.50	about you
	stand	4.69	7.78	stood	5.29	7.60	over there
	keep	5.55	8.99	kept	4.75	7.65	a dollar
	drive	3.85	7.15	drove	4.08	7.22	a Ford
	send	4.30	7.85	sent	4.25	8.14	a letter
Mean		*3.9*	*6.7*		*3.7*	*6.1*	
SD		*1.8*	*2.3*		*1.9*	*2.6*	
Range		*1.1 - 6.7*	*2.9 - 9.9*		*0.0 - 6.4*	*0.0 - 9.5*	

Table 3

Regular and Irregular Verbs in the Past Tense Production and Judgment Tasks

Note. Verb stems and past tense forms for the 20 regular and 16 irregular verbs on which analyses were based. The relative word frequencies for stem (unmarked) and past tense forms are reported for the FK and AP frequency counts (see text). The raw frequencies were augmented by 1 and then natural-log transformed. The rightmost column displays the complements/adjuncts used in the verb presentation sentences.

Verb Stem	Expected Regularized Past Tense Form	Examples of Plausible Irregularized Past Tense Form	Verb Complement/ Adjunct
Novel Regulars			
spuff	spuffed		on TV
traff	traffed		at Mom
dotch	dotched		a bicycle
stoff	stoffed		against it
cug	cugged		about that
slub	slubbed		a computer
trab	trabbed		inside it
pob	pobbed		a table
plag	plagged		a nail
crog	crogged		above them
vask	vasked		a handkerchief
prass	prassed		a window
brop	bropped		at Diane
prap	prapped		a shoe
satch	satched		onto shore
grush	grushed		alongside Eric
plam	plammed		a tooth
tunch	tunched		a car
scur	scurred		a bean
scash	scashed		at work
Novel Irregulars			
strink	strinked	strank / strunk	a horse
frink	frinked	frank / frunk	after dinner
strise	strised	striz / stroze	without them
treave	treaved	trove / treft	a tree
crive	crived	criv / crove	in France
shrell	shrelled	shrelt / shrold	around Chris
vurn	vurned	vurnt	in Boston
steeze	steezed	stoze	our clock
shrim	shrimmed	shram / shrum	at home
trine	trined	trin / trone	our house
preed	preeded	pred	a puzzle
cleed	cleeded	cled	opposite them
sheel	sheeled	shelt	among them
blide	blided	blid / blode	with her
cleep	cleeped	clept	after work
prend	prended	prent	a mouse
shreep	shreeped	shrept	our child
drite	drited	drit / drote	a corner

Table 4

Novel Verbs in the Past Tense Production and Judgment Tasks

Note. Verb stems for the 20 novel regular and 18 novel irregular verbs on which analyses were based. Also shown are their expected regularized and plausible irregularized past tense forms, and the complements/adjuncts used in sentences for their presentation to subjects.

		FCL	*RBA*	*Control Subjects (Non-Fluent Aphasics)*	*JLU*	*HFL, JHA, JMO, WBO, APE*	*Control Subjects (Fluent Aphasics)*
n		1	1	12	1	5	8
Verb Type							
Regular	*(look)*						
Correct	*(looked)*	20 (4)	20 (4)	98 (236)	90 (18)	85 (85)	99 (159)
Multiple suffix	*(lookeded)*	0	0	0	5 (1)	0	0
Syllabic suffix	*(look-id)*	0	0	0	0	0	0
Ing-suffixed	*(looking)*	40 (8)	10 (2)	0	0	0	0
En-suffixed	*(looken)*	0	0	0	0	0	0
S-suffixed	*(looks)*	0	0	0	0	0	0
Unmarked	*(look)*	30 (6)	40 (8)	1 (2)	5 (1)	8 (8)	0
Irregularized	*(lak)*	0	0	0	0	0	0
Ed-suffixed distortion	*(yooked)*	0	5 (1)	0	0	1 (1)	0
Distortion	*(yook)*	0	5 (1)	0	0	1 (1)	0
Word intrusion	*(hooked, watched)*	0	0	.4 (1)	0	1 (1)	.6 (1)
Word substitution	*(hook, saw)*	5 (1)	10 (2)	0	0	2 (2)	0
Ing-suffixed substitution	*(hooking, seeing)*	0	5 (1)	0	0	0	0
En-suffixed substitution	*(hooken, seen)*	0	0	0	0	0	0
S-suffixed substitution	*(hooks, sees)*	0	0	0	0	0	0
No response		5 (1)	5 (1)	.4 (1)	0	0	0
Other errors		0	0	0	0	2 (2)	0
Irregular	*(dig)*						
Correct	*(dug)*	69 (11)	25 (4)	96 (185)	63 (10)	73 (58)	98 (126)
Over-regularized	*(digged)*	0	13 (2)	.5 (1)	19 (3)	5 (4)	0
Multiple suffix	*(diggeded)*	0	0	0	0	0	0
Syllabic suffix	*(dig-id)*	0	0	0	0	0	0
Suffixed irregular	*(dugged)*	0	6 (1)	0	0	1 (1)	0
Ing-suffixed	*(digging)*	13 (2)	0	0	0	0	0
En-suffixed	*(diggen)*	6 (1)	0	0	0	0	0
S-suffixed	*(digs)*	0	0	0	0	0	0
Unmarked	*(dig)*	13 (2)	44 (7)	.5 (1)	0	9 (7)	.8 (1)
Over-irregularized	*(dag)*	0	0	3 (5)	6 (1)	4 (3)	.8 (1)
Ed-suffixed distortion	*(drigged)*	0	0	0	0	0	0
Distortion	*(drig, cug)*	0	0	0	0	6 (5)	0
Word intrusion	*(tugged, worked)*	0	0	0	0	0	0
Word substitution	*(tug, work)*	0	0	0	6 (1)	3 (2)	0
Ing-suffixed substitution	*(tugging, working)*	0	0	0	0	0	0
En-suffixed substitution	*(done, worken)*	0	0	0	0	0	0
S-suffixed substitution	*(tugs,works)*	0	0	0	0	0	0
No response		0	0	0	0	0	0
Other errors		0	13 (2)	0	6 (1)	0	0
Novel Regular	*(plag)*						
Correct	*(plagged)*	5 (1)	NA	95 (228)	80 (16)	70 (56)	94 (150)
Multiple suffix	*(plaggeded)*	0	NA	0	0	0	0
Syllabic suffix	*(plag-id)*	0	NA	.4 (1)	0	1 (1)	1 (2)
Ing-suffixed	*(plagging)*	15 (3)	NA	0	0	0	0
En-suffixed	*(plaggen)*	0	NA	0	0	0	0
S-suffixed	*(plags)*	0	NA	0	0	0	0
Unmarked	*(plag)*	35 (7)	NA	.4 (1)	0	10 (7)	0
Irregularized	*(plog)*	0	NA	2 (5)	0	1 (1)	2 (3)
Ed-suffixed distortion	*(pragged)*	10 (2)	NA	1 (3)	10 (2)	6 (4)	2 (3)
Distortion	*(splag, splug)*	0	NA	0	0	3 (2)	0
Word intrusion	*(plucked)*	5 (1)	NA	.4 (1)	10 (2)	4 (3)	.6 (1)
Word substitution	*(flag, pluck)*	0	NA	.4 (1)	0	0	.6 (1)
Ing-suffixed substitution	*(plucking)*	0	NA	0	0	0	0
En-suffixed substitution	*(plucken)*	0	NA	0	0	0	0

S-suffixed substitution	*(plucks)*	0	NA	0	0	0	0
No response		20 (4)	NA	0	0	0	0
Other errors		10 (2)	NA	0	0	9 (6)	0
Novel Irregular	*(crive)*						
Regularized	*(crived)*	28 (5)	NA	58 (126)	72 (13)	53 (38)	64 (92)
Irregularized	*(crove)*	0	NA	32 (70)	0	17 (12)	29 (42)
Suffixed irregularization	*(croved)*	0	NA	1 (3)	0	0	.7 (1)
Multiple suffix	*(criveded)*	0	NA	0	0	1 (1)	.7 (1)
Syllabic suffix	*(crive-id)*	0	NA	0	0	1 (1)	0
Ing-suffixed	*(criving)*	0	NA	0	0	0	0
En-suffixed	*(criven)*	0	NA	0	0	0	0
S-suffixed	*(crives)*	0	NA	0	0	0	0
Unmarked	*(crive)*	17 (3)	NA	5 (10)	11 (2)	18 (13)	3 (5)
Ed-suffixed distortion	*(clived)*	0	NA	.5 (1)	6 (1)	4 (3)	0
Distortion	*(clive, clove)*	0	NA	0	0	0	0
Word intrusion	*(arrived)*	0	NA	1 (3)	6 (1)	3 (2)	1 (2)
Word substitution	*(arrive, live)*	22 (4)	NA	.9 (2)	6 (1)	0	.7 (1)
Ing-suffixed substitution	*(arriving)*	0	NA	0	0	0	0
En-suffixed substitution	*(arriven, driven)*	0	NA	0	0	0	0
S-suffixed substitution	*(arrives)*	0	NA	0	0	0	0
No response		28 (5)	NA	0	0	0	0
Other errors		6 (1)	NA	.5 (1)	0	3 (2)	0

Table 5.

Responses in Past Tense Production Task: Non-Fluent and Fluent Aphasics

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

		HFL	*JHA*	*JMO*	*WBO*	*APE*	*Mean*	*Control Subjects*
n		1	1	1	1	1	5	8
Verb Type								
Regular	*(look)*							
Correct	*(looked)*	70 (14)	85 (17)	90 (18)	90 (18)	90 (18)	85 (85)	99 (159)
Multiple suffix	*(lookeded)*	0	0	0	0	0	0	0
Syllabic suffix	*(look-id)*	0	0	0	0	0	0	0
Ing-suffixed	*(looking)*	0	0	0	0	0	0	0
En-suffixed	*(looken)*	0	0	0	0	0	0	0
S-suffixed	*(looks)*	0	0	0	0	0	0	0
Unmarked	*(look)*	30 (6)	0	5 (1)	0	5 (1)	8 (8)	0
Irregularized	*(lak)*	0	0	0	0	0	0	0
Ed-suffixed distortion	*(yooked)*	0	0	0	5 (1)	0	1 (1)	0
Distortion	*(yook)*	0	0	0	0	5 (1)	1 (1)	0
Word intrusion	*(hooked, watched)*	0	5 (1)	0	0	0	1 (1)	.6 (1)
Word substitution	*(hook, saw)*	0	5 (1)	0	5 (1)	0	2 (2)	0
Ing-suffixed substitution	*(hooking, seeing)*	0	0	0	0	0	0	0
En-suffixed substitution	*(hooken, seen)*	0	0	0	0	0	0	0
S-suffixed substitution	*(hooks, sees)*	0	0	0	0	0	0	0
No response		0	0	0	0	0	0	0
Other errors		0	5 (1)	5 (1)	0	0	2 (2)	0
Irregular	*(dig)*							
Correct	*(dug)*	38 (6)	63 (10)	88 (14)	88 (14)	88 (14)	73 (58)	98 (126)
Over-regularized	*(digged)*	0	6 (1)	6 (1)	13 (2)	0	5 (4)	0
Multiple suffix	*(diggeded)*	0	0	0	0	0	0	0
Syllabic suffix	*(dig-id)*	0	0	0	0	0	0	0
Suffixed irregular	*(dugged)*	0	0	0	0	6 (1)	1 (1)	0
Ing-suffixed	*(digging)*	0	0	0	0	0	0	0
En-suffixed	*(diggen)*	0	0	0	0	0	0	0
S-suffixed	*(digs)*	0	0	0	0	0	0	0
Unmarked	*(dig)*	31 (5)	6 (1)	6 (1)	0	0	9 (7)	.8 (1)
Over-irregularized	*(dag)*	0	13 (2)	0	0	6 (1)	4 (3)	.8 (1)
Ed-suffixed distortion	*(drigged)*	0	0	0	0	0	0	0
Distortion	*(drig, cug)*	25 (4)	6 (1)	0	0	0	6 (5)	0
Word intrusion	*(tugged, worked)*	0	0	0	0	0	0	0
Word substitution	*(tug, work)*	6 (1)	6 (1)	0	0	0	3 (2)	0
Ing-suffixed substitution	*(tugging, working)*	0	0	0	0	0	0	0
En-suffixed substitution	*(done, worken)*	0	0	0	0	0	0	0
S-suffixed substitution	*(tugs,works)*	0	0	0	0	0	0	0
No response		0	0	0	0	0	0	0
Other errors		0	0	0	0	0	0	0
Novel Regular	*(plag)*							
Correct	*(plagged)*	45 (9)	NA	50 (10)	100 (20)	85 (17)	70 (56)	94 (150)
Multiple suffix	*(plaggeded)*	0	NA	0	0	0	0	0
Syllabic suffix	*(plag-id)*	0	NA	5 (1)	0	0	1 (1)	1 (2)
Ing-suffixed	*(plagging)*	0	NA	0	0	0	0	0
En-suffixed	*(plaggen)*	0	NA	0	0	0	0	0
S-suffixed	*(plags)*	0	NA	0	0	0	0	0
Unmarked	*(plag)*	30 (6)	NA	5 (1)	0	0	10 (7)	0
Irregularized	*(plog)*	0	NA	5 (1)	0	0	1 (1)	2 (3)
Ed-suffixed distortion	*(pragged)*	5 (1)	NA	5 (1)	0	10 (2)	6 (4)	2 (3)
Distortion	*(splag, splug)*	10 (2)	NA	0	0	0	3 (2)	0
Word intrusion	*(plucked)*	0	NA	10 (2)	0	5 (1)	4 (3)	.6 (1)
Word substitution	*(flag, pluck)*	0	NA	0	0	0	0	.6 (1)
Ing-suffixed substitution	*(plucking)*	0	NA	0	0	0	0	0
En-suffixed substitution	*(plucken)*	0	NA	0	0	0	0	0
S-suffixed substitution	*(plucks)*	0	NA	0	0	0	0	0

No response		0	NA	0	0	0	0	0
Other errors		10 (2)	NA	20 (4)	0	0	9 (6)	0
Novel Irregular	*(crive)*							
Regularized	*(crived)*	22 (4)	NA	61 (11)	67 (12)	61 (11)	53 (38)	64 (92)
Irregularized	*(crove)*	6 (1)	NA	28 (5)	6 (1)	28 (5)	17 (12)	29 (42)
Suffixed irregularization	*(croved)*	0	NA	0	0	0	0	.7 (1)
Multiple suffix	*(criveded)*	0	NA	6 (1)	0	0	1 (1)	.7 (1)
Syllabic suffix	*(crive-id)*	0	NA	0	6 (1)	0	1 (1)	0
Ing-suffixed	*(criving)*	0	NA	0	0	0	0	0
En-suffixed	*(criven)*	0	NA	0	0	0	0	0
S-suffixed	*(crives)*	0	NA	0	0	0	0	0
Unmarked	*(crive)*	56 (10)	NA	0	11 (2)	6 (1)	18 (13)	3 (5)
Ed-suffixed distortion	*(clived)*	11 (2)	NA	0	0	6 (1)	4 (3)	0
Distortion	*(clive, clove)*	0	NA	0	0	0	0	0
Word intrusion	*(arrived)*	6 (1)	NA	0	6 (1)	0	3 (2)	1 (2)
Word substitution	*(arrive, live)*	0	NA	0	0	0	0	.7 (1)
Ing-suffixed substitution	*(arriving)*	0	NA	0	0	0	0	0
En-suffixed substitution	*(arriven, driven)*	0	NA	0	0	0	0	0
S-suffixed substitution	*(arrives)*	0	NA	0	0	0	0	0
No response		0	NA	0	0	0	0	0
Other errors		0	NA	6 (1)	6 (1)	0	3 (2)	0

Table 6.

Responses in Past Tense Production Task: The Five Fluent Aphasics with Less Circumscribed Lesions.

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

	Non-Fluent Aphasics	Controls (Non-Fluent Aphasics)	Fluent Aphasics	Controls (Fluent Aphasics)
n	2	12	6	8
Regular				
scowl	50 (1)	100 (12)	67 (4)	100 (8)
tug	0 (0)	100 (12)	100 (6)	100 (8)
flush	50 (1)	100 (12)	83 (5)	100 (8)
cram	50 (1)	100 (12)	100 (6)	100 (8)
mar	0 (0)	100 (12)	67 (4)	100 (8)
chop	0 (0)	92 (11)	100 (6)	100 (8)
flap	0 (0)	100 (12)	83 (5)	100 (8)
stalk	0 (0)	100 (12)	83 (5)	100 (8)
cook	0 (0)	100 (12)	100 (6)	100 (8)
scour	50 (1)	100 (12)	67 (4)	100 (8)
slam	0 (0)	100 (12)	67 (4)	100 (8)
cross	0 (0)	100 (12)	100 (6)	100 (8)
rush	0 (0)	100 (12)	100 (6)	100 (8)
shrug	0 (0)	100 (12)	67 (4)	100 (8)
rob	50 (1)	100 (12)	100 (6)	100 (8)
drop	50 (1)	100 (12)	100 (6)	100 (8)
look	50 (1)	100 (12)	83 (5)	100 (8)
walk	0 (0)	100 (12)	100 (6)	100 (8)
stir	50 (1)	92 (11)	67 (4)	88 (7)
soar	0 (0)	83 (10)	83 (5)	100 (8)
Mean	***20***	***98***	***86***	***99***
Irregular				
swim	0 (0)	100 (12)	100 (6)	100 (8)
dig	50 (1)	100 (12)	67 (4)	100 (8)
swing	50 (1)	83 (10)	67 (4)	100 (8)
cling	50 (1)	100 (12)	83 (5)	100 (8)
wring	100 (2)	75 (9)	83 (5)	88 (7)
bend	0 (0)	100 (12)	50 (3)	100 (8)
bite	50 (1)	100 (12)	83 (5)	100 (8)
feed	50 (1)	100 (12)	67 (4)	100 (8)
come	50 (1)	100 (12)	67 (4)	100 (8)
make	0 (0)	92 (11)	67 (4)	100 (8)
give	100 (2)	100 (12)	100 (6)	100 (8)
think	50 (1)	100 (12)	50 (3)	100 (8)
stand	50 (1)	100 (12)	83 (5)	100 (8)
keep	100 (2)	100 (12)	83 (5)	100 (8)
drive	50 (1)	100 (12)	83 (5)	100 (8)
send	0 (0)	92 (11)	100 (6)	88 (7)
Mean	***47***	***96***	***71***	***98***
Novel Regular				
spuff	0 (0)	92 (11)	80 (4)	100 (8)
traff	0 (0)	100 (12)	100 (5)	88 (7)
dotch	0 (0)	100 (12)	60 (3)	100 (8)
stoff	0 (0)	100 (12)	60 (3)	100 (8)
cug	0 (0)	100 (12)	100 (5)	100 (8)
slub	0 (0)	100 (12)	60 (3)	88 (7)
trab	0 (0)	92 (11)	40 (2)	88 (7)
pob	0 (0)	92 (11)	40 (2)	100 (8)

plag	0 (0)	100 (12)	60 (3)	88 (7)
crog	0 (0)	100 (12)	60 (3)	100 (8)
vask	0 (0)	67 (8)	80 (4)	75 (6)
prass	0 (0)	100 (12)	80 (4)	100 (8)
brop	0 (0)	100 (12)	60 (3)	100 (8)
prap	0 (0)	92 (11)	100 (5)	100 (8)
satch	0 (0)	92 (11)	60 (3)	75 (6)
grush	0 (0)	100 (12)	80 (4)	100 (8)
plam	0 (0)	92 (11)	100 (5)	100 (8)
tunch	0 (0)	100 (12)	80 (4)	100 (8)
scur	100 (1)	100 (12)	100 (5)	100 (8)
scash	0 (0)	83 (10)	40 (2)	75 (6)
Mean	***5***	***95***	*72*	***94***
Novel Irregular				
Regularized				
strink	0 (0)	33 (4)	40 (2)	25 (2)
frink	0 (0)	42 (5)	40 (2)	25 (2)
strise	0 (0)	58 (7)	0 (0)	63 (5)
treave	0 (0)	83 (10)	100 (5)	100 (8)
crive	100 (1)	67 (8)	100 (5)	75 (6)
shrell	0 (0)	100 (12)	80 (4)	100 (8)
vurn	0 (0)	100 (12)	80 (4)	100 (8)
steeze	0 (0)	67 (8)	80 (4)	63 (5)
shrim	0 (0)	33 (4)	100 (5)	63 (5)
trine	100 (1)	75 (9)	60 (3)	88 (7)
preed	100 (1)	33 (4)	40 (2)	38 (3)
cleed	100 (1)	33 (4)	40 (2)	38 (3)
sheel	0 (0)	75 (9)	60 (3)	88 (7)
blide	100 (1)	67 (8)	20 (1)	63 (5)
cleep	0 (0)	50 (6)	40 (2)	50 (4)
prend	0 (0)	33 (4)	40 (2)	50 (4)
shreep	0 (0)	58 (7)	80 (4)	88 (7)
drite	0 (0)	42 (5)	20 (1)	38 (3)
Mean	***28***	***58***	*57*	***64***
Irregularized				
strink	0 (0)	58 (7)	40 (2)	75 (6)
frink	0 (0)	58 (7)	20 (1)	75 (6)
strise	0 (0)	25 (3)	40 (2)	25 (2)
treave	0 (0)	17 (2)	0 (0)	0 (0)
crive	0 (0)	33 (4)	0 (0)	25 (2)
shrell	0 (0)	0 (0)	0 (0)	0 (0)
vurn	0 (0)	0 (0)	0 (0)	0 (0)
steeze	0 (0)	8 (1)	0 (0)	25 (2)
shrim	0 (0)	58 (7)	0 (0)	38 (3)
trine	0 (0)	25 (3)	20 (1)	13 (1)
preed	0 (0)	42 (5)	20 (1)	50 (4)
cleed	0 (0)	25 (3)	20 (1)	13 (1)
sheel	0 (0)	25 (3)	0 (0)	0 (0)
blide	0 (0)	33 (4)	0 (0)	38 (3)
cleep	0 (0)	50 (6)	20 (1)	50 (4)
prend	0 (0)	33 (4)	20 (1)	25 (2)
shreep	0 (0)	42 (5)	20 (1)	13 (1)
drite	0 (0)	42 (5)	20 (1)	63 (5)
Mean	***0***	***32***	*13*	***29***

Table 7.
Responses in the Past Tense Production Task: By Item.
Note. Percent correct responses (and number of subjects who produced a correct response in parentheses). The results for the non-fluent aphasics on novel verbs are based solely on FCL's responses, because RBA could not perform the task for novel verbs. Similarly, the results for the fluent aphasics on novel verbs are based on the scores of 5 aphasics because JHA could not perform the task for novel verbs.

VERB STEM	STEM FREQ. FK	STEM FREQ. AP	PAST TENSE	PAST TENSE FREQ. FK	PAST TENSE FREQ. AP
Regular					
flow	2.64	4.7	flowed	1.61	3.91
view	2.94	6.34	viewed	1.1	5.42
weigh	1.61	5.34	weighed	2.48	5.56
slow	2.2	6.31	slowed	2.56	5.66
owe	2.4	5.72	owed	2.56	5.84
slip	2.08	5.12	slipped	3.3	6.96
sigh	0.69	0.69	sighed	3.14	3.43
tie	2.3	5.35	tied	2.64	5.97
stay	4.58	8.13	stayed	4.11	7.01
love	3.99	7.04	loved	3.83	6.11
die	4.06	7.33	died	4.16	9.02
learn	4.43	7.38	learned	4.01	7.2
pray	2.56	5.99	prayed	2.2	5.23
use	5.43	8.83	used	4.93	8.38
try	4.92	8.55	tried	4.8	8.5
show	5.31	8.63	showed	4.93	8.74
seem	5.44	7.5	seemed	5.74	7.69
Mean	*3.39*	*6.41*		*3.42*	*6.51*
SD	*1.48*	*1.97*		*1.29*	*1.63*
Range	*0.7 - 5.4*	*0.7 - 8.8*		*1.1 - 5.7*	*3.4 - 9.0*
Irregular					
lend	2.64	5.47	lent	1.39	4.80
hide	2.94	6.23	hid	1.95	5.34
stride	1.61	1.39	strode	2.40	3.93
cling	1.95	4.01	clung	2.64	4.01
swear	2.40	4.09	swore	2.71	4.30
sweep	2.08	4.75	swept	3.00	6.19
flee	0.69	6.10	fled	3.14	7.41
slide	2.20	4.54	slid	3.22	5.23
buy	4.23	8.56	bought	3.50	7.56
spend	3.99	7.93	spent	3.71	8.05
drive	3.85	7.15	drove	4.08	7.22
send	4.30	7.85	sent	4.25	8.14
speak	4.71	7.69	spoke	4.47	8.60
keep	5.55	8.99	kept	4.75	7.65
hold	4.98	8.35	held	4.84	8.42
leave	5.26	8.64	left	5.06	8.86
feel	5.31	8.44	felt	5.71	7.94
Mean	*3.45*	*6.48*		*3.58*	*6.69*
SD	*1.49*	*2.15*		*1.18*	*1.73*
Range	*0.7 - 5.6*	*1.4 - 9.0*		*1.4 - 5.7*	*3.9 - 8.9*

Table 8

Regular and Irregular Verbs in the Past Tense Reading Task

Note. The relative word frequencies for stem (unmarked) and past tense forms are reported for the FK and AP frequency counts (see text). The raw frequencies were augmented by 1 and then natural-log transformed.

		FCL	*CIG*	*WRO*	*LDO*	*PJ*	*KCL*	*NSL*	*HTA*	*NWH*	*Mean*	*Control Subjects*
n		1	1	1	1	1	1	1	1	1	9	8
Verb Type												
Regular	*(look)*											
Correct	*(looked)*	41 (7)	0	6 (1)	18 (3)	35 (6)	41 (7)	29 (5)	29 (5)	76 (13)	31 (47)	100 (136)
Multiple suffix	*(lookeded)*	0	0	0	0	0	0	0	0	0	0	0
Syllabic suffix	*(look-id)*	0	0	0	0	0	0	0	0	0	0	0
Ing-suffixed	*(looking)*	0	24 (4)	0	0	6 (1)	6 (1)	0	0	0	4 (6)	0
En-suffixed	*(looken)*	0	0	0	0	0	0	0	0	0	0	0
S-suffixed	*(looks)*	0	0	0	6 (1)	0	0	0	0	0	.7 (1)	0
Unmarked	*(look)*	24 (4)	0	47 (8)	53 (9)	24 (4)	29 (5)	35 (6)	35 (6)	24 (4)	30 (46)	0
Irregularized	*(lak)*	0	0	0	0	0	0	0	0	0	0	0
Ed-suffixed Distortion	*(yooked)*	6 (1)	0	0	0	0	0	0	0	0	.7 (1)	0
Distortion	*(yook)*	6 (1)	0	0	0	0	0	0	0	0	.7 (1)	0
Word intrusion	*(hooked, watched)*	6 (1)	6 (1)	0	6 (1)	18 (3)	0	12 (2)	6 (1)	0	6 (9)	0
Word substitution	*(hook, saw)*	18 (3)	24 (4)	35 (6)	18 (3)	12 (2)	6 (1)	0	24 (4)	0	15 (23)	0
Ing-suffixed substitution	*(hooking, seeing)*	0	18 (3)	0	0	0	0	0	0	0	2 (3)	0
En-suffixed substitution	*(hooken, seen)*	0	0	0	0	0	0	0	0	0	0	0
S-suffixed substitution	*(hooks, sees)*	0	0	6 (1)	0	0	0	0	0	0	.7 (1)	0
No response		0	29 (5)	6 (1)	0	6 (1)	0	0	6 (1)	0	5 (8)	0
Other errors		0	0	0	0	0	18 (3)	24 (4)	0	0	5 (7)	0
Irregular	*(dig)*											
Correct	*(dug)*	56 (9)	24 (4)	35 (6)	65 (11)	71 (12)	71 (12)	24 (4)	24 (4)	94 (16)	51 (78)	99 (135)
Over-regularized	*(digged)*	0	0	0	0	0	0	0	0	0	0	0
Multiple suffix	*(diggeded)*	0	0	0	0	0	0	0	0	0	0	0
Syllabic suffix	*(dig-id)*	0	0	0	0	0	0	0	0	0	0	0
Suffixed irregular	*(dugged)*	0	0	0	0	6 (1)	0	0	0	0	.7 (1)	0
Ing-suffixed	*(digging)*	0	18 (3)	0	0	0	0	6 (1)	0	0	3 (4)	0
En-suffixed	*(diggen)*	0	6 (1)	0	0	0	0	0	6 (1)	0	1 (2)	0
S-suffixed	*(digs)*	0	0	0	0	0	0	0	6 (1)	0	.7 (1)	0
Unmarked	*(dig)*	19 (3)	0	12 (2)	18 (3)	18 (3)	12 (2)	24 (4)	18 (3)	0	13 (20)	.7 (1)
Over-irregularized	*(dag)*	0	0	0	0	0	0	0	0	0	0	0
Ed-suffixed distortion	*(drigged)*	0	0	0	0	0	0	0	0	0	0	0
Distortion	*(drig, cug)*	0	0	0	0	0	6 (1)	6 (1)	0	0	1 (2)	0
Word intrusion	*(tugged, worked)*	6 (1)	0	0	0	0	0	0	0	0	.7 (1)	0
Word substitution	*(tug, work)*	12 (2)	12 (2)	47 (8)	18 (3)	6 (1)	0	18 (3)	24 (4)	6 (1)	16 (24)	0

Ing-suffixed substitution	*(tugging, working)*	0	18 (3)	0	0	0	0	0	0	0	2 (3)	0
En-suffixed substitution	*(done, worken)*	6 (1)	0	0	0	0	0	0	0	0	.7 (1)	0
S-suffixed substitution	*(tugs)*	0	0	0	0	0	0	6 (1)	0	0	.7 (1)	0
No response		0	24 (4)	6 (1)	0	0	0	6 (1)	12 (2)	0	5 (8)	0
Other errors		0	0	0	0	0	12 (2)	12 (2)	12 (2)	0	4 (6)	0

Table 9.

Responses in Past Tense Reading Task: Non-Fluent 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.

		NSL	*KCL*	*HTA*	*NWH*	*Mean*
n		1	1	1	1	4
Verb Type						
Regular	*(look)*					
Correct	*(look)*	53 (9)	71 (12)	47 (8)	100 (17)	68 (46)
Regularized	*(looked)*	0	12 (2)	12 (2)	0	6 (4)
Multiple suffix	*(lookeded)*	0	0	0	0	0
Syllabic suffix	*(look-id)*	0	0	0	0	0
Ing-suffixed	*(looking)*	0	0	0	0	0
En-suffixed	*(looken)*	0	0	0	0	0
S-suffixed	*(looks)*	0	0	0	0	0
Irregularized	*(lak)*	0	0	0	0	0
Ed-suffixed distortion	*(yooked)*	0	0	0	0	0
Distortion	*(yook)*	12 (2)	0	6 (1)	0	4 (3)
Word intrusion	*(hooked,watched)*	0	0	0	0	0
Word substitution	*(hook, saw)*	18 (3)	6 (1)	24 (4)	0	12 (8)
Ing-suffixed substitution	*(hooking, seeing)*	0	0	0	0	0
En-suffixed substitution	*(hooken, seen)*	0	0	0	0	0
S-suffixed substitution	*(hooks, sees)*	0	0	0	0	0
No response		6 (1)	0	6 (1)	0	3 (2)
Other errors		12 (2)	12 (2)	6 (1)	0	7 (5)
Irregular	*(dig)*					
Correct	*(dig)*	41 (7)	76 (13)	65 (11)	100 (17)	71 (48)
Irregularized	*(dug)*	0	0	0	0	0
Over-regularized	*(digged)*	0	0	0	0	0
Multiple suffix	*(diggeded)*	0	0	0	0	0
Syllabic suffix	*(dig-id)*	0	0	0	0	0
Suffixed irregular	*(dugged)*	0	0	0	0	0
Ing-suffixed	*(digging)*	0	0	0	0	0
En-suffixed	*(diggen)*	0	0	0	0	0
S-suffixed	*(digs)*	0	0	0	0	0
Over-irregularized	*(dag)*	0	0	0	0	0
Ed-suffixed distortion	*(drigged)*	0	0	0	0	0
Distortion	*(drig, cug)*	24 (4)	18 (3)	6 (1)	0	12 (8)
Word intrusion	*(tugged, worked)*	0	0	0	0	0
Word substitution	*(tug, work)*	18 (3)	0	12 (2)	0	7 (5)
Ing-suffixed substitution	*(tugging, working)*	0	0	0	0	0
En-suffixed substitution	*(done, worken)*	0	0	0	0	0
S-suffixed substitution	*(tugs, works)*	0	0	0	0	0
No response		12 (2)	0	18 (3)	0	7 (5)
Other errors		6 (1)	6 (1)	0	0	3 (2)

Table 10.

Responses in Stem Reading Task: Non-Fluent Aphasics

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

		LBR	YHY	RHH	HFL	APE	Mean	Control Subjects
n		1	1	1	1	1	5	8
Verb Type								
Regular	*(look)*							
Correct	*(looked)*	12 (2)	94 (16)	24 (4)	82 (14)	94 (16)	61 (52)	100 (136)
Multiple suffix	*(lookeded)*	0	0	0	0	0	0	0
Syllabic suffix	*(look-id)*	0	0	0	0	0	0	0
Ing-suffixed	*(looking)*	18 (3)	0	0	0	0	4 (3)	0
En-suffixed	*(looken)*	0	0	0	0	0	0	0
S-suffixed	*(looks)*	0	0	0	0	0	0	0
Unmarked	*(look)*	0	6 (1)	0	6 (1)	0	2 (2)	0
Irregularized	*(lak)*	0	0	0	0	0	0	0
Ed-suffixed distortion	*(yooked)*	0	0	0	0	6 (1)	1 (1)	0
Distortion	*(yook)*	12 (2)	0	24(4)	0	0	7 (6)	0
Word intrusion	*(hooked, watched)*	6 (1)	0	12 (2)	0	0	4 (3)	0
Word substitution	*(hook, saw)*	35 (6)	0	41 (7)	6 (1)	0	16 (14)	0
Ing-suffixed substitution	*(hooking, seeing)*	18 (3)	0	0	0	0	4 (3)	0
En-suffixed substitution	*(hooken, seen)*	0	0	0	0	0	0	0
S-suffixed substitution	*(hooks, sees)*	0	0	0	0	0	0	0
No response		0	0	0	0	0	0	0
Other errors		0	0	0	6 (1)	0	1 (1)	0
Irregular	*(dig)*							
Correct	*(dug)*	24 (4)	82 (14)	12 (2)	71 (12)	88 (15)	55 (47)	99 (135)
Over-regularized	*(digged)*	0	0	0	0	0	0	0
Multiple suffix	*(diggeded)*	0	0	0	0	0	0	0
Syllabic suffix	*(dig-id)*	0	0	0	0	0	0	0
Suffixed irregular	*(dugged)*	0	0	0	0	0	0	0
Ing-suffixed	*(digging)*	6 (1)	0	0	0	0	1 (1)	0
En-suffixed	*(diggen)*	0	0	0	0	0	0	0
S-suffixed	*(digs)*	0	0	0	0	0	0	0
Unmarked	*(dig)*	0	6 (1)	0	0	0	1 (1)	.7 (1)
Over-irregularized	*(dag)*	0	0	6 (1)	0	0	1 (1)	0
Ed-suffixed distortion	*(drigged)*	0	0	0	0	0	0	0
Distortion	*(drig, cug)*	35 (6)	12 (2)	47 (8)	12 (2)	6 (1)	22 (19)	0
Word intrusion	*(tugged, worked)*	0	0	6 (1)	0	0	1 (1)	0
Word substitution	*(tug, work)*	29 (5)	0	29 (5)	12 (2)	6 (1)	15 (13)	0
Ing-suffixed substitution	*(tugging, working)*	0	0	0	0	0	0	0
En-suffixed substitution	*(done, worken)*	0	0	0	0	0	0	0
S-suffixed substitution	*(tugs,works)*	0	0	0	0	0	0	0
No response		0	0	0	0	0	0	0
Other errors		6 (1)	0	0	6 (1)	0	2 (2)	0

Table 11.

Responses in Past Tense Reading Task: Fluent Aphasics

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

	Non-Fluent Aphasics	Fluent Aphasics	Control Subjects
Regular			
flowed	11 (1)	60 (3)	100 (8)
viewed	22 (2)	60 (3)	100 (8)
weighed	33 (3)	100 (5)	100 (8)
slowed	11 (1)	40 (2)	100 (8)
owed	33 (3)	80 (4)	100 (8)
slipped	33 (3)	60 (3)	100 (8)
sighed	22 (2)	40 (2)	100 (8)
tied	44 (4)	60 (3)	100 (8)
stayed	11 (1)	60 (3)	100 (8)
loved	56 (5)	60 (3)	100 (8)
died	67 (6)	100 (5)	100 (8)
learned	33 (3)	40 (2)	100 (8)
prayed	11 (1)	60 (3)	100 (8)
used	67 (6)	60 (3)	100 (8)
tried	33 (3)	60 (3)	100 (8)
showed	22 (2)	40 (2)	100 (8)
seemed	11 (1)	60 (3)	100 (8)
Mean	***31***	***61***	***100***
Irregular			
lent	89 (8)	60 (3)	100 (8)
hid	33 (3)	40 (2)	100 (8)
strode	22 (2)	80 (4)	100 (8)
clung	38 (3)	40 (2)	100 (8)
swore	56 (5)	60 (3)	100 (8)
swept	33 (3)	60 (3)	100 (8)
fled	33 (3)	20 (1)	100 (8)
slid	56 (5)	20 (1)	88 (7)
bought	89 (8)	20 (1)	100 (8)
spent	67 (6)	80 (4)	100 (8)
drove	56 (5)	60 (3)	100 (8)
sent	56 (5)	80 (4)	100 (8)
spoke	44 (4)	80 (4)	100 (8)
kept	33 (3)	60 (3)	100 (8)
held	56 (5)	60 (3)	100 (8)
left	56 (5)	60 (3)	100 (8)
felt	56 (5)	60 (3)	100 (8)
Mean	***51***	***55***	***99***

Table 12.

Responses in the Past Tense Reading Task: By Item.

Percent correct responses (and number of subjects who produced a correct response in parentheses). The percentage for one item (*clung*) was based on 8 rather than 9 non-fluent aphasics because of a presentation error of this item to one non-fluent aphasic.

		LBR	*RHH*	*YHY*	*Mean*
n		1	1	1	3
Verb Type					
Regular	*(look)*				
Correct	*(look)*	41 (7)	29 (5)	100 (17)	57 (29)
Regularized	*(looked)*	0	0	0	0
Multiple suffix	*(lookeded)*	0	0	0	0
Syllabic suffix	*(look-id)*	0	0	0	0
Ing-suffixed	*(looking)*	6 (1)	0	0	2 (1)
En-suffixed	*(looken)*	0	0	0	0
S-suffixed	*(looks)*	0	0	0	0
Irregularized	*(lak)*	0	0	0	0
Ed-suffixed distortion	*(yooked)*	0	0	0	0
Distortion	*(yook)*	12 (2)	53 (9)	0	22 (11)
Word intrusion	*(hooked,watched)*	6 (1)	0	0	2 (1)
Word substitution	*(hook, saw)*	29 (5)	18 (3)	0	16 (8)
Ing-suffixed substitution	*(hooking, seeing)*	0	0	0	0
En-suffixed substitution	*(hooken, seen)*	0	0	0	0
S-suffixed substitution	*(hooks, sees)*	0	0	0	0
No response		0	0	0	0
Other errors		6 (1)	0	0	2 (1)
Irregular	*(dig)*				
Correct	*(dig)*	24 (4)	18 (3)	100 (17)	47 (24)
Irregularized	*(dug)*	0	0	0	0
Over-regularized	*(digged)*	0	0	0	0
Multiple suffix	*(diggeded)*	0	0	0	0
Syllabic suffix	*(dig-id)*	0	0	0	0
Suffixed irregular	*(dugged)*	0	0	0	0
Ing-suffixed	*(digging)*	6 (1)	0	0	2 (1)
En-suffixed	*(diggen)*	0	0	0	0
S-suffixed	*(digs)*	0	0	0	0
Over-irregularized	*(dag)*	0	0	0	0
Ed-suffixed distortion	*(drigged)*	0	0	0	0
Distortion	*(drig, cug)*	12 (2)	47 (8)	0	20 (10)
Word intrusion	*(tugged, worked)*	0	12 (2)	0	4 (2)
Word substitution	*(tug, work)*	35 (6)	18 (3)	0	18 (9)
Ing-suffixed substitution	*(tugging, working)*	0	0	0	0
En-suffixed substitution	*(done, worken)*	0	0	0	0
S-suffixed substitution	*(tugs, works)*	0	6 (1)	0	2 (1)
No response		0	0	0	0
Other errors		24 (4)	0	0	8 (4)

Table 13.

Responses in Stem Reading Task: Fluent Aphasics

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

	Non-Fluent Aphasics	Fluent Aphasics
Regular		
flow	75 (3)	33 (1)
view	75 (3)	67 (2)
weigh	50 (2)	67 (2)
slow	50 (2)	33 (1)
owe	50 (2)	67 (2)
slip	75 (3)	33 (1)
sigh	25 (1)	67 (2)
tie	50 (2)	67 (2)
stay	100 (4)	33 (1)
love	75 (3)	100 (3)
die	50 (2)	67 (2)
learn	75 (3)	67 (2)
pray	100 (4)	67 (2)
use	75 (3)	67 (2)
try	75 (3)	33 (1)
show	100 (4)	33 (1)
seem	50 (2)	67 (2)
Mean	***68***	***57***
Irregular		
lend	25 (1)	67 (2)
hide	75 (3)	33 (1)
stride	75 (3)	33 (1)
cling	100 (4)	33 (1)
swear	75 (3)	33 (1)
sweep	100 (4)	67 (2)
flee	75 (3)	33 (1)
slide	75 (3)	33 (1)
buy	75 (3)	33 (1)
spend	50 (2)	100 (3)
drive	75 (3)	67 (2)
send	25 (1)	67 (2)
speak	75 (3)	33 (1)
keep	50 (2)	33 (1)
hold	75 (3)	33 (1)
leave	75 (3)	33 (1)
feel	100 (4)	67 (2)
Mean	***71***	*47*

Table 14.
Responses in the Stem Reading Task: By Item.
Percent correct responses (and number of subjects who produced a correct response in parentheses).

Verb Stem	Stem Freq. FK	Stem Freq. AP	Regular Past Tense Form	Regular Past Tense Freq. FK	Regular Past Tense Freq. AP	Irregular Past Tense Form	Irregular Past Tense Freq. FK	Irregular Past Tense Freq. AP	Verb Complement/ Adjunct
Doublet Verbs									
light	3.30	5.82	lighted	1.95	2.89	lit	2.30	4.69	a match
burn	4.01	7.58	burned	2.77	6.57	burnt	0.00	0.69	our dinner
dwell	2.71	4.53	dwelled	0.00	1.95	dwelt	0.69	1.61	at home
spill	1.95	5.04	spilled	1.10	4.95	spilt	0.00	0.00	a drink
kneel	2.48	3.93	kneeled	1.10	2.08	knelt	2.08	3.58	upon it
dream	3.22	5.35	dreamed	2.08	4.47	dreamt	0.69	1.79	about Hillary
creep	2.83	4.71	creeped	0.00	0.00	crept	2.30	3.76	underneath it
leap	2.48	4.52	leaped	2.94	4.88	leapt	1.10	2.83	with joy
tread	1.39	3.89	treaded	0.00	0.00	trod	0.00	1.79	on grass
sneak	1.61	4.63	sneaked	1.61	3.30	snuck	0.00	0.00	into school
spin	2.77	5.48	spinned	0.00	0.00	spun	2.71	4.39	our wool
slink	0.00	1.61	slinked	0.00	0.00	slunk	0.00	0.00	in late
slay	0.69	4.06	slayed	0.00	0.00	slew	0.00	0.00	a dragon
strive	2.64	5.36	strived	0.00	1.39	strove	1.61	2.56	for success
dive	1.95	4.75	dived	1.61	3.50	dove	0.00	3.09	into it
shine	3.33	5.13	shined	0.00	2.56	shone	0.00	0.00	with sweat
Mean	*2.34*	*4.77*		*0.95*	*2.41*		*0.84*	*1.92*	
SD	*1.04*	*1.22*		*1.09*	*2.11*		*1.02*	*1.69*	
Range	*0.0-4.01*	*1.61-7.58*		*0.0-2.94*	*0.0-6.57*		*0.0-2.71*	*0.0-4.69*	

Table 15.

Doublet Verbs in the Past Tense Judgment Task

Note. Verb stems and past tense forms for the 16 doublet verbs on which analyses were based. The relative word frequencies for stem (unmarked) and past tense forms are reported for the FK and AP frequency counts (see text). The raw frequencies were augmented by 1 and then natural-log transformed. The rightmost column displays the complements/adjuncts used in the verb presentation sentences.

Subject	Sex	Age	Years of Education	Pre-Morbid Handedness
HT	M	-	-	-
VS	F	51	-	-
JG	M	70	12	R
BM	F	55	-	-
F38	F	38	16	R
SJD	F	47	16+	-
FM	M	44	12	R

Table 16
Aphasic Subjects from Previous Studies of Regular and Irregular Processing: Demographic Data.
Note: Age is calculated at the date of testing regular and irregular inflection.

Subject	Frontal	Basal Ganglia	Insula	Inferior Parietal	Temporal
		Non-Fluent Aphasics			
FCL	MFG, IFG w/ Broca's	Pu, GP (not CN)	yes	no	no
RBA	Broca's	no?	no?	no?	TI
CIG	Broca's +	Pu (not GP, CN)	yes	Ant SMG	no
WRO	Broca's +	Pu	yes	no	Ant STG
LDO	Broca's +	Pu, GP, CN	yes	Ant SMG	TI, Wernicke's
PJ	yes	-	-	yes	STG
KCL	yes	-	-	yes	-
NSL	yes	-	-	yes	-
HTA	yes	yes	no?	no?	Wernicke's +
NWH	yes	-	-	yes	-
BMC	yes	Pu, GP	yes	Ant SMG	TI, Wernickes +
		Fluent Aphasics			
JLU	no	no	no?	Post SMG, AG	Wernicke's
HFL	no	Pu, GP, CN	yes	no	TI
JHA	slight	no?	no?	SMG, AG	no?
JMO	no	Pu	yes	SMG, AG	TI, STG, MTG, ITG
WBO	slight	no	no	no	Ant TP
APE	no	Pu, GP	yes	SMG, AG	STG, MTG, ITG
LBR	no?	-	-	yes	yes
RHH	-	-	-	-	-
YHY	-	-	-	-	-

Table 17.

Aphasic Subjects: Summary of Lesioned Brain Structures.

Note. All lesioned structures a in the left hemisphere. None of the subjects had any known right hemisphere damage. yes = region reported as damaged in lesion description; no = region reported as being not damaged; no? = no damage reported in lesion description; slight = reported damage is minimal; Ant = Anterior; Post = Posterior; MFG = Middle Frontal Gyrus; IFG = Inferior Frontal Gyrus; Broca's = Broca's area; Broca's + = Broca's area plus nearby frontal structures; Pu = Putamen; GP = Globus Pallidus; CN = Caudate Nucleus; SMG = Supramarginal Gyrus; AG = Angular Gyrus; TI = Temporal Isthmus; TP = Temporal pole; STG = Superior Temporal Gyrus; MTG = Middle Temporal Gyrus; ITG = Inferior Temporal Gyrus; Wernicke's = Wernicke's area; Wernicke's + = Wernicke's area plus nearby temporal lobe regions. A dash (-) indicates no information is available.