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Neural correlates of lexicon and grammar: Evidence from the production, reading, and judgment of inflection in aphasia

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Abstract

Are the linguistic forms that are memorized in the mental lexicon and those that are specified by the rules of grammar subserved by distinct neurocognitive 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-mechanism view, the computation of both past tense types depends on associative memory. Neurological double dissociations between regulars and irregulars strengthen the duaNSl-system view. The computation of real and novel, regular and irregular past tense forms was investigated in 20 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. These patterns held even when measures of frequency, phonological complexity, articulatory difficulty, and other factors were held constant. The data support the view that the memorized words of the mental lexicon are subserved by a brain system involving left 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.

Keywords: Language; Neurolinguistics; Brain; Grammar; Lexicon; Past tense; Regular; Irregular; Morphology; Aphasia; Agrammatism; Anomia; Declarative memory; Procedural memory; Dual-system; Single-system

1. 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 forms 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 encompasses rules or constraints that govern the sequential and hierarchical combination

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of lexical forms into predictably structured complex 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, 1995; Pinker, 1994).

These two language capacities have been explained by two competing theoretical frameworks. "Dual-system" theories posit distinct cognitive or neural components for the two capacities (Chomsky, 1965, 1995; Damasio & Damasio, 1992; Fodor, 1983; Pinker, 1994). On this view, the learning, representation, and/or processing of words in a rote or an associative memory is subserved by one or more components, which may be specialized and dedicated ("domain-specific") to these functions (Bloom, 1994; Chomsky, 1965, 1995; Fodor, 1983; Forster, 1979; Levelt, 1989, 1992; Markman & Hutchinson, 1984; Pinker, 1994; Seidenberg, 1985; Swinney, 1982; Waxman & Markow, 1996). The use of stored words has been posited to depend especially on left posterior regions, particularly temporal and temporo-parietal structures (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 that have been posited to be innately specified (Chomsky, 1965, 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, 1992; Grodzinsky, 2000; Zurif, 1995), although this has been controversial, in particular regarding the comprehension of syntax (e.g., Hickok, 2000).

In contrast, "single-mechanism" (single-system) theories posit that the learning and use of the words and rules of language depend upon a single computational system that has a relatively broad anatomic distribution (Bates & MacWhinney, 1989; Elman, 1996; MacDonald, Pearlmutter, & Seidenberg, 1994; MacWhinney & Bates, 1989; Rumelhart & McClelland, 1986; Seidenberg, 1997). This system is general-purpose ("domain-general") in that it also subserves non-language functions. There is no categorical distinction between non-compositional and compositional forms on this view. 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, 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 anterior or posterior portions of the left hemisphere (Alexander, 1997; Caplan, 1987, 1992; Dronkers, Pinker, & Damasio, 2000; 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 omit neither 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 appropriate morphological affixes (e.g., *-ed*) and function words. Non-fluent aphasics 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, particularly in receptive language. Non-fluent aphasia is associated with damage to left frontal structures (Caplan, 1992; Caramazza et al., 1981; Dronkers et al., 2000; Goodglass, 1993; Goodglass & Wingfield, 1997; Grodzinsky, 2000; Grodzinsky & Finkel, 1998).

Electrophysiology. Event-related potential (ERP) studies seem to be consistent with 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, 1983), and has been linked to left temporal lobe structures (Nobre, Allison, & McCarthy, 1994; Papanicolaou, Simos, & Basile, 1998; Simos, Basile, & Papanicolaou, 1997). In contrast, disruptions of syntactic processing can yield early (150–500 ms) left anterior negativities (Friederici, Pfeifer, & Hahne, 1993; Hagoort, Wassenaar, & Brown, 2003; Neville, Nicol, Barss, Forster, & Garrett, 1991)—i.e., "LANs." These have been linked to rule-based automatic computations (Friederici, Hahne, & Mecklinger, 1996; Hahne & Friederici, 1999) and left frontal structures (Friederici, Hahne, & von Cramon, 1998; Friederici, von Cramon, & Kotz, 1999). LANs have been elicited cross-linguistically by violations of syntactic word-order (Friederici, 2002; Friederici et al., 1993; Neville et al., 1991; Newman, Izvorski, Davis, Neville, & Ullman, 1999) and morpho-syntax (Coulson, King, & Kutas, 1998; Friederici & Frisch, 2000; Kaan, 2002; Kutas & Hillyard, 1983; Münte, Heinze, & Mangun, 1993; Osterhout & Mobley, 1995; Rosler, Putz, Friederici, & Hahne, 1993). However, not all studies examining these types of violations have reported LANs (Ainsworth-Darnell, Shulman, & Boland, 1998; Allen, Badecker, & Osterhout, 2003; Hagoort & Brown, 1999; McKinnon & Osterhout, 1996; Osterhout, Bersick, & McLaughlin, 1997; Osterhout & Mobley, 1995). It is not clear at this point why LANs have been found by some studies and not by others, even for the same types of violation (Osterhout & Mobley, 1995).

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 a variety of lexical and semantic tasks (for a summary, see e.g., Ullman, 2004), such as semantic categorical judgments of auditorily presented word pairs (Wise, Chollet, Hadar, Friston, & Hoffner, 1991), naming colors, faces, animals, and tools (Damasio et al., 1996; Martin, Haxby, Lalonde, Wiggs, & Ungerleider, 1995; Martin, Wiggs, Ungerleider, & Haxby, 1996), and same/different judgments on sentence pairs containing identical syntax, but differing in one word (Bookheimer, Zeffiro, Gaillaird, & Theodore, 1993). In contrast, preferential activation in portions of Broca's area has been elicited by a variety of tasks designed to probe syntactic processing (Bookheimer et al., 1993; Caplan, Alpert, & Waters, 1998; Dapretto & Bookheimer, 1999; Embick, Marantz, Miyashita, O'Neil, & Sakai, 2000; Friederici, Ruschemeyer, Hahne, & Fiebach, 2003; Indefrey et al., 1999; Indefrey, Hagoort, Herzog, Seitz, & Brown, 2001; Kang, Constable, Gore, & Avrutin, 1999; Knoesche, Maess, & Friederici, 2000; Moro et al., 2001; Ni et al., 2000; Stromswold, Caplan, Alpert, & Rauch, 1996). For example, Broca's area activation has been found when subjects gave acceptability judgments to syntactically more complex sentences, as compared to syntactically less complex sentences (Caplan et al., 1998; Stromswold et al., 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, the picture is by no means crystal clear. Thus there is also evidence 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 the substitution 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, 1992; Dronkers et al., 2000; 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 processing difficulties (Hagoort & Kutas, 1995; Kaan, Harris, Gibson, & Holcomb, 2000; Osterhout, McLaughlin, & Bersick, 1997), in particular with aspects of controlled processing (Friederici et al., 1996; Friederici, Mecklinger, Spencer, Steinhauer, & Donchin, 2001; Hahne & Friederici, 1999). P600s do not appear to depend on frontal brain structures, and may involve both basal ganglia and posterior regions (Friederici & Kotz, 2003;

Friederici et al., 1998, 1999; Friederici, Kotz, Werheid, Hein, & von Cramon, 2003; Ullman, 2001b).

Neuroimaging. Syntactic processing has been linked to anterior superior temporal cortex (Dapretto & Bookheimer, 1999; Friederici, Ruschemeyer, et al., 2003; Meyer, Friederici, & von Cramon, 2000; Newman, Pancheva, Ozawa, Neville, & Ullman, 2001; Ni et al., 2000). Additionally, 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). Finally, activation in certain frontal regions is associated with the search, selection, or retrieval of word sounds and meanings (Buckner & Peterson, 1996; Buckner & Wheeler, 2001; Thompson-Schill, D'Esposito, Aguirre, & Farah, 1997).

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 productive approach to investigate the brain bases of lexicon and grammar may thus be to examine language phenomena in which factors other than lexical and grammatical involvement can be controlled for.

2. Regular and irregular morphology

We and others have therefore investigated the dual-system/single-system controversy by examining a set of 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 focused 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. This research has examined the memory/rule distinction with respect to both 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 from existing 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, 1982; Kiparsky, 1982; Mohanan, 1986; Selkirk, 1982; Stanners, Neiser, Hernon, & Hall, 1979; Stemberger & MacWhinney, 1986, 1988). Although these two types of morphology can be dissociated (Badecker & Caramazza, 1989; Coslett, 1986; Garrett, 1980, 1982; Laudanna, Badecker, & Caramazza, 1992; Miceli & Caramazza, 1988), they also share many similarities (Di Sciullo & Williams, 1987; Halle, 1973; Halle & Marantz, 1993; Lieber, 1992; Stanners et al., 1979; Stemberger & MacWhinney, 1986, 1988).

In particular, both inflectional and derivational morphology contain a range of types of morpho-phonological 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 phonological complexity (e.g., *slept/slipped*), word frequency, and other factors (Pinker, 1991, 1994; Spencer, 1991).

The regular/irregular distinction in English past tense has been particularly 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 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 list of items in rote memory, whereas regular forms (e.g., *looked*, *played*, and *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 been posited that the partially productive irregulars (e.g., *sang*, *rang*, *kept*, and *wept*) are also stored in memory (Bybee & Moder, 1983; Bybee & Slobin, 1982; Vennemann, 1971). It has also been proposed (Halle & Marantz, 1993) that most irregulars are composed from stem and affix (e.g., *keep* + -*t*), with a memorized link between the stem and affix of irregulars, thus enabling the addition of the correct "irregular" affix (e.g., -0 in *sang* or -*t* in *kept*), as well as the application of "stem-readjustment" rules that are tied to particular words (e.g., *i–a* in *sing–sang*).

An alternative theory, which consistent with a single system view, posits that regulars and irregulars are learned in and computed over an associative memory which can be modeled by a 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), ranging 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. Reflecting this perspective, 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, 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 et al., 1992; Pinker, 1991, 1999; Pinker & Prince, 1988; Pinker & Ullman, 2002; Ullman, Corkin, et al., 1997). 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). This memory system learns the mappings of individual morphological forms (e.g., *sing–sang*) and the patterns common to the mappings of different forms (e.g., in *sing–sang*, *spring–sprang*), and can then generalize these patterns to new forms (*spling–splang*). Thus, unlike a rote memory, this memory is productive, though the extent of its productivity remains unclear. 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*, and *happy*) with suffixes (e.g., *-ed*, *-s*, and *-ness*) (Chomsky, 1965; Marcus, Brinkmann, Clahsen, Wiese, & Pinker, 1995; Pinker, 1991; Ullman, Corkin, et al., 1997). The computation of an inflectional or derivational morphophonological 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, 1999; Pinker & Ullman, 2002).

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 also other categories of morphological transformations, including those that clearly involve overt affixes but are 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 crucially 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 likely to be memorized (Ullman, 1993, in press).

It has been argued that linguistic, psycholinguistic, and developmental evidence from inflectional and derivational morphology support a dual-system view. Distinct components have been implicated in the use of (largely) unproductive non-default versus productive default inflection by investigations of a number of linguistic phenomena, including English past tense and plural inflection (Pinker, 1999; Pinker & Ullman, 2002), German participle and plural inflection (Clahsen, 1999; Marcus et al., 1995; Sonnenstuhl, Eisenbeiss, & Clahsen, 1999), and Japanese adjectival inflection (Fujiwara & Ullman, 1999). For example, a number of 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, suggesting the memorization of irregular but not regular past tense forms (Prasada, Pinker, & Snyder, 1990; Seidenberg & Bruck, 1990; Ullman, 1993, 1999). Similar results have been obtained in children (van der Lely & Ullman, 2001). These findings have been interpreted as indicating that irregular but not regular past tense forms are retrieved from memory.

However, other studies have reported frequency effects for regulars (Marchman, 1997; Sereno & Jongman, 1997; Stemberger & MacWhinney, 1988). Moreover, 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, 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). (For further discussion also see Pinker & Ullman, 2002; Ullman, 1999).

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, 1999). 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, 1999). 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.

The principles and architecture of connectionist models of reading aloud have recently been extended to a connectionist model of morphology (Joanisse & Seidenberg, 1998, 1999). Like connectionist models of reading aloud, the model proposed by Joanisse and Seidenberg contains distinct representations for semantics and phonology, which are, respectively, assumed to rely on temporal- and frontal-lobe structures. Simulations of damage to the semantic representations led to worse performance producing past tenses of irregulars than of regulars and -*ed*-suffixed novel verbs. Simulations of damage to phonology led to worse performance producing past tenses of novel than of regular and irregular verbs, but *no reliable difference* between regulars and irregulars. In the initial report (Joanisse & Seidenberg, 1998), phonological lesions actually 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, and were more phonologically complex, there were not significantly more errors on regulars. Only when the authors examined a subset of the most severely lesioned simulations could they find some which yielded reliably worse performance at regulars than irregulars.

Thus lesions to this model yielded reliable double dissociations between irregulars and novel verbs, but, crucially, *not* between irregulars and regulars—even when the regulars had lower frequency and were more phonologically complex. The demonstration of reliably worse performance on regulars than irregulars by frontal patients would therefore not appear to be consistent with extant simulations of this model, even when regulars are somewhat more phonologically complex and of lower frequency than irregulars, let alone when regulars and irregulars are matched on these factors. Although it has been argued that, according to the model, the generally greater phonological complexity of regulars than irregulars (e.g., *stopped* vs. *sang*) can indeed explain frontal patients' worse performance at regulars (Bird, Lambon Ralph, Seidenberg, McClelland, & Patterson, 2003; McClelland & Patterson, 2002), the simulations reported by Joanisse and Seidenberg (1999) do not directly support this view. Thus it is not clear how much less frequent or more phonologically complex regulars must be as compared to irregulars for the model to predict worse performance at regulars. Importantly, in two of the three studies presented below, the regulars and irregulars are the *same* set as examined by Joanisse and Seidenberg, and thus it their model should *not* expect worse performance at regulars on these items. In the third study, the regulars and irregulars are directly matched on phonological complexity and frequency, and so presumably the model would expect no regular deficit whatsoever.

2.1. 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-mechanism 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 separate systems: one being more important for irregulars, and lexical memory for generally, than for regulars and grammar, and tied to posterior structures; and the other being more important for regulars and grammar than irregulars and lexical memory, and tied to frontal structures. Here we briefly summarize the literature testing for neural dissociations between regular and irregular morphological forms. For additional discussion, see Marslen-Wilson and Tyler (1998), Clahsen (1999), Pinker (1999), Ullman (2001a), Ullman (2001c), Pinker and Ullman (2002), McClelland and Patterson (2002), and Ullman (2004).

Aphasia. A number of studies have found that non-fluent aphasics (with left anterior damage) are worse at producing (Ullman, Corkin, et al., 1997; Ullman et al., 1994), reading out loud (Badecker & Caramazza, 1987, 1991; Coslett, 1986; Marin, Saffran, & Schwartz, 1976; Ullman, Corkin, et al., 1997; Ullman, Hickok, & Pinker, 1995) writing from dictation (Coslett, 1988), and repeating (Badecker & Caramazza, 1987) regular than irregular English past tense forms, even with efforts to control for factors such as phonological complexity, frequency, and word length. Such aphasics also have greater difficulty reading (Coslett, 1986; Marin et al., 1976) and writing (Coslett, 1988) regular than irregular plurals, and show past tense/stem priming for irregular but not regular past tenses (e.g., *rats* vs. *mice*) (Marslen-Wilson & Tyler, 1997). Moreover, evidence suggests that they are slower at detecting the difference between spoken regular past tenses and their stems (*called/call*), relative to matched mono-morphemic words (*bald/ball*) and irregular pairs (*wrote/write*) (Tyler, Randall, & Marslen-Wilson, 2002). However, one recent study of production, repetition, reading, and judgment of English past tense forms reported that most (though *not* all) of the regular disadvantage disappeared when phonological complexity and other factors are controlled for (Bird et al., 2003). (See below for more discussion of this study.) Across other languages the picture is mixed: while Japanese patients show a relative deficit of regulars in a judgment task of derivational morphology (Hagiwara, Ito, Sugioka, Kawamura, & Shiota, 1999), such a deficit has not been observed in aspects of German and Greek inflection (Penke, Janssen, & Krause, 1999; Tsapkini, Jarema, & Kehayia, 2001). Fluent aphasics (with left posterior damage) show a different pattern than non-fluent aphasics, eliciting worse performance at irregular than regular English past tenses in production (Ullman, Corkin, et al., 1997) and priming tasks (Marslen-Wilson & Tyler, 1998; Marslen-Wilson & Tyler, 1997; Tyler, de Mornay-Davies, et al., 2002). Similarly, Japanese posterior aphasics are worse at judging irregular than regular derivational forms (Hagiwara et al., 1999). Finally, a recent study reported a patient with a relative deficit of irregular past tenses and mono-morphemic word forms, but *no* semantic deficits (Miozzo, 2003), counter to the predictions of the connectionist model proposed by Joanisse and Seidenberg.

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 syntax and to frontal/basal-ganglia circuits (Ullman, in press; Ullman, Corkin, et al., 1997; Ullman et al., 1994, 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 (Arnold, Hyman, Flory, Damasio, & Hoesen, 1991; Kemper, 1994). 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 English—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; Obler, 1981). 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, Corkin, et al., 1997). Similarly, Italian AD patients have been shown to have more difficulty producing Italian irregular than regular present tense and past participle forms (Cappa & Ullman, 1998; Walenski, Sosta, Cappa, & Ullman, under review).

Semantic dementia is associated with the progressive and severe degeneration of inferior and lateral temporal lobe regions (Mummery et al., 2000). The disorder results in the loss of lexical knowledge, with spared syntactic and phonological abilities (Bozeat, Lambon Ralph, Patterson, Garrard, & Hodges, 2000; Breedin & Saffran, 1999; Graham, Patterson, & Hodges, 1999; Hodges, Graham, & Patterson, 1995). Patients with semantic dementia yield a pattern like that of AD patients. They have more trouble producing and recognizing irregular than regular and -*ed*-suffixed novel past tenses, and the degree of their impairment on irregulars correlates with their performance on an independent lexical memory task (Patterson, Lambon Ralph, Hodges, & McClelland, 2001).

Parkinson's disease (PD) is linked to 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 (via the thalamus). 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 also appear to have difficulty with syntactic processing, both in comprehension (Grossman, Carvell, et al., 1993; 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, 1993; 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 production of regular and irregular English 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 circuits in grammatical rule use (Ullman, in press; Ullman, Corkin, et al., 1997).

Although Huntington's disease (HD) is like PD in causing degeneration of the basal ganglia, it strikes different portions of these structures. Unlike in PD, this damage results in the disinhibition of frontal areas receiving basal-ganglia projections (Young & Penney, 1993). This leads to the unsuppressible movements (chorea, a type of hyperkinesia) found in HD. Patients with HD show the opposite pattern to those with PD not only in the type of movement impairment (suppressed vs. unsuppressed), but also in the type of errors on -*ed*-suffixed forms (Ullman, in press; Ullman, Corkin, et al., 1997). HD patients produce forms like *walkeded*, *plaggeded*, and *dugged*—but not analogous errors on irregulars like *dugug* or *keptet*, suggesting that the errors are not attributable to articulatory or motor deficits. Rather the data suggest unsuppressed -*ed*-suffixation. This conclusion is strengthened by the finding that the production rate of these over-suffixed forms correlates with the degree of chorea, across patients.

The contrasting findings in PD and HD, linking movement and -*ed*-suffixation in two distinct types of impairments related to two types of basal-ganglia damage, strongly implicate frontal/basal-ganglia circuits in -*ed*-suffixation. They also support the hypothesis that these structures underlie grammatical composition as well as movement, and suggest that they play similar computational roles in the two domains. The double dissociations between AD and semantic dementia on the one hand, and PD on the other, 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). Although the irregular deficit shown by the AD and semantic dementia patients is consistent with the Joanisse and Seidenberg model, the regular deficit of the PDs is not. Note, however, that 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.

Electrophysiology. Event-Related Potential (ERP) studies have examined regular and irregular inflectional morphology in German (Penke et al., 1997; Weyerts, Penke, Dohrn, Clahsen, & Münte, 1997), Italian (Gross, Say, Kleingers, Münte, & Clahsen, 1998), Spanish (Rodriguez-Fornells, Munte, & Clahsen, 2002), and English (Allen et al., 2003; Münte, Say, Clahsen, Schiltz, & Kutas, 1999; Newman et al., 1999; Newman, Ullman, Pancheva, Waligura, & Neville, under revision; Ullman, Newman, Izvorski, & Neville, 2000). All these studies have found distinct ERP patterns for regulars and irregulars. Although the specific results have varied somewhat, certain trends emerge from this work. [Here we focus on the studies employing violations (Allen et al., 2003; Gross et al., 1998; Newman et al., 1999; Penke et al., 1997; Rodriguez-Fornells, Clahsen, Lleo, Zaake, & Munte, 2001; Ullman et al., 2000; Weyerts et al., 1997) rather than those examining priming (Münte et al., 1999; Rodriguez-Fornells et al., 2002).]

First of all, inappropriate regular affixation (i.e., anomalous addition or omission of the affix) generally leads to a LAN. Violations of regular past tense (presentation of a stem form in a past tense context; e.g., *Yesterday I walk over there*) have been found to elicit a LAN in English (Newman et al., 1999, under revision; Ullman et al., 2000). Moreover, this LAN does not appear to differ in topography from the LAN elicited by syntactic word-order anomalies, underscoring common neural mechanisms for regular morpho-phonology and aspects of syntax (Newman et al., 1999; Ullman et al., 2000). In German (Penke et al., 1997; Weyerts et al., 1997) and Italian (Gross et al., 1998), incorrectly adding a regular affix to an irregular verb has also resulted in anterior negativities, as compared to the signal elicited by the correct irregular form. However, it is important to point out that not all studies examining inappropriate affixation have found LANs. Thus a recent study of English (Allen et al., 2003) did not observe a LAN in response to regular past tense forms presented in future tense sentence contexts.

Inappropriate irregular inflection has led to a somewhat different pattern than inappropriate regular inflection, eliciting either N400-like negativities (Newman et al., 1999; Ullman et al., 2000; Weyerts et al., 1997) or no effect at all (Allen et al., 2003; Gross et al., 1998; Penke et al., 1997). Finally, P600 effects have been observed for both regular *and* irregular past tense violations in studies of English (Allen et al., 2003; Newman et al., 1999, under revision; Ullman et al., 2000), although these effects have differed somewhat in latency (Allen et al., 2003) or distribution (Newman et al., 1999; Ullman et al., 2000) between the two verb types. P600s were not reported in the ERP studies of inflection in German and Italian (Gross et al., 1998; Penke et al., 1997; Weyerts et al., 1997), perhaps because the stimuli contained violations only of morpho-phonology, not of morpho-syntax.

Thus previous ERP experiments of regular/irregular morphology have yielded somewhat mixed results, although certain trends seem to be emerging: if any LAN or N400 effects are found at all, violations of regular inflection elicit the former, while violations of irregular inflection elicit the latter; if violations of morpho-syntax are also present, P600s are found for both types of forms.

Neuroimaging. Several PET and fMRI studies have examined regular and irregular morphology, both in English past tense production (Jaeger et al., 1996; Ullman, Bergida, & O'Craven, 1997), and in German inflection (Beretta et al., 2003; Indefrey et al., 1997). All of these studies have reported differential activation in frontal and temporal regions for the two types of forms. However, the data are difficult to interpret because the specific regions have varied to some extent across the studies. Here we summarize and briefly discuss the data from the studies of English inflection.

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 discussion of this study, see Seidenberg and Hoeffner (1998) and Beretta et al. (2003).

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 et al., 1997). Twenty seconds of regulars (10 verbs) were followed by 20 s of fixation (looking at a cross on the screen), 20 s of irregulars (10 verbs), and 20 s 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: 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). 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 ms 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 (250–310 ms). 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 ms). 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 (Pinker & Ullman, 2002; Ullman, 2001c; Ullman, Corkin, et al., 1997).

In sum, although the data are not without problems, results from previous studies strongly suggest neurocognitive dissociations between regulars and irregulars. However, there have been few experiments that test for double dissociations between regulars and irregulars and that also examine links between the two types of inflectional forms and both their posited underlying linguistic capacities and particular brain regions—namely, studies that test for links among regulars, grammar, and left frontal cortex, and among irregulars, lexicon, and temporal/temporo-parietal cortex. It is thus important to further probe for these double dissociations and their neuroanatomical and functional bases. Moreover, testing for dissociations across several tasks, in both expressive and receptive language, and examining novel as well as real regular and irregular forms, should reveal the generality of any effects, and should help tease apart the competing theoretical perspectives. For example, because the Joanisse and Seidenberg model assumes that a novel form has no meaning, "the only way to generate its past tense is by analogy to known phonological forms" (Joanisse & Seidenberg, 1999). On this view, regularized and irregularized novel forms (e.g., *plag–plagged* and *crive–crove*) should pattern together. They should both be impaired following frontal-lobe damage, and should both be spared following temporal-lobe damage. This contrasts with the pattern predicted by the dual-system perspective explored here, which expect novel and real irregulars to pattern together (e.g., both impaired with temporal lesions) and novel and real regulars to pattern together (e.g., both impaired with frontal lesions).

3. Three studies

Here we report three in-depth investigations 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 tested 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, Bergida et al. (1997). 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 processing of real and novel regular past tenses (e.g., *looked*, *plagged*), and of over-regularizations (*digged*), relies 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 as compared to 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.

3.1. Study 1: Regular and irregular past tense production

We predicted that agrammatic non-fluent aphasics should have more trouble producing (i.e., generating) 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, when these patients do 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. That is, they should have more trouble producing irregular than regular past tenses, for both real and novel verbs. Given their impairment of lexical memory and hypothesized relative sparing of grammar, these patients should be likely to produce over-regularizations. (Note that 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 classification of "anomic aphasia.")

3.2. 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 should 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.

3.3. Study 3: Regular and irregular past tense judgment

If non-fluent and fluent aphasics show similar impairments in receptive language as in expressive language, then one should also find double dissociations between regular and irregular past tense judgment. Agrammatic non-fluent aphasics should give lower acceptability ratings to real and novel –*ed*-suffixed forms (e.g., *walked*, *plagged*, and *crived*) than to real and novel irregular forms (e.g., *dug*, *crove*), as compared to normal control subjects. Anomic fluent aphasics, by contrast, should show the opposite pattern.

In sum, we made the following predictions: (1) Agrammatic non-fluent aphasics were expected to have greater difficulty producing, reading, and judging regular and other -*ed*-suffixed past tenses as compared to real or novel irregulars. (2) Anomic fluent aphasics should show the opposite pattern.

4. 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.

4.1. Aphasic subjects

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. 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, and 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 Appendix A.

4.2. 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 four subjects participating in both groups) to match the non-fluent and fluent aphasic

Table 1
Aphasic subjects: Summary of demographic data

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

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

Table 2
Aphasic subjects: Clinical and behavioral summary

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

Note. Only past tense tests that were successfully carried out are indicated. Legend: prod, past tense production task; read, past tense reading task; and judg, past tense judgment task.

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; 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 (12–16 years) was similar to that of that of the four aphasic subjects (12, 14, 16, and 16 years).

5. Study 1: Past tense production

5.1. Method

5.1.1. Materials

Subjects were presented with 80 verbs. (1) Twenty "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. Thus they and their phonological neighbors (i.e., those with similar-sounding stems) 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*, and *bend*). (2) Twenty *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) Twenty *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 existing irregulars. Their expected pasts are therefore regular (*plag–plagged*). (4) Twenty *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*, cf. *drive–drove*, *jive–jived*).

Three irregular verbs (*hit*, *split*, and *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 past tense and stem forms cannot be distinguished in production data. 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 (see Ullman, Corkin, et al., 1997). Thus a total of 20 regular, 16 irregular, 20 novel regular, and 18 novel irregular verbs were tested and analyzed in this 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*, cf. *hide–hid*, *ride–rode*), and thus they and their neighbors do not follow a consistent stem-past mapping. We have argued elsewhere 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 (Ullman, 1993, 2001a, in press). 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 one 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: $t(34) = 3.561$, $p = .001$). Analyses were carried out with and without holding frequency constant (see below).

The verbs were selected according to a number of 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*, and *have*). Third, we eliminated verbs which were judged to be possible denominals (derived from a noun: $ring_N \rightarrow ring_V$), de-adjectivals (derived

Table 3
Regular and irregular verbs in the past tense production and judgment tasks

Verb stem	Stem frequency FK	Stem frequency AP	Past tense form	Past tense frequency FK	Past tense frequency 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	

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.

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

Table 4
Novel verbs in the past tense production and judgment tasks

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

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.

"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 uninflected 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 explicit 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. The full list of verbs, together with their complements or adjuncts, is displayed in Tables 3 and 4.

5.1.2. Procedure

The items were randomized by a 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 and transcribing 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 audiotaped. 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, Corkin, et al. (1997), 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 appropriate past tense forms (*looked*, *dug*) were counted as correct; 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 form. Regularized (*crived*) and irregularized (*crove*) past tense forms were tabulated separately as two types of appropriate 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 categorized into several types. For all verb types, responses which repeated the presented stem were classified as unmarked (e.g., *look–look*, *keep–keep*, *spuff–spuff*, and *crive–crive*). -*Ed*-suffixed stems of existing irregular verbs were classified as over-regularizations (e.g., *digged*, *keeped*). Responses with more than one instance of the -*ed*-affix attached to the presented stem were coded as multiply-suffixed forms, irrespective of the type of verb (e.g., *look–looke-ded*, *keep-keepeded*, *spuff–spuffeded*, and *crive–criveded*). Existing irregular past tense forms with an attached -*ed* affix were coded as suffixed irregulars (e.g., *dugged*). Novel irregulars which were both irregularized and -*ed*-suffixed were classified as suffixed irregularizations (e.g., *crive–croved*). An existing irregular yielding an incorrect past tense form whose morpho-phonological transformation was similar to that of one or more other irregulars was classified as an over-irregularization (e.g., *think–thank*, *fling–flang*, cf. *sink–sank*, *sing–sang*). Past tense forms that were produced for existing or novel regulars, but which were plausible irregularizations, were classified as irregularizations (e.g., *prap–prup*). Forms where the -*ed*-suffix was incorrectly syllabified, and was attached to the presented stem, were coded as syllabically suffixed (e.g., *look–look–id*, *keep–keep–id*).

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 were coded as -*ing* suffixed substitutions (e.g., *cook–tooking*, *dig–sinking*). Responses in which an-*en*-affix was added to the presented stem were coded as-*en*-suffixed (e.g., *bite–bitten*, *make–maken*). 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 an -*s*-affix was added to the presented stem were coded as -*s*-suffixed (e.g., *show–shows*). 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*, and *strink–stroke*), irregularly inflected words (e.g., *feed–fled*, *bend–spent*, *slam–shut*, and *rush–ran*), and forms with one or more affixes other than -*ed* -*ing*, or -*s* (e.g., *flow–flowers*). As is 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*, and *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 -*ing*-suffixed distortions.) Typically, distortions were phonologically very similar to the presented stimulus and/or the target past tense. Possible examples include *swing–swin*, *keep–kep*, *drive–drovbe*, and *shreep–shroke*. Distortions which were -*ed*-suffixed were labeled as -ed-suffixed distortions (e.g., *stoff–stroffed*, *drite–strited*, and *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, were 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*).

5.2. Results and discussion

5.2.1. Non-fluent aphasia

We tested two non-fluent aphasics who were able to perform the past tense production task (Tables 5 and 7). 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.

5.2.1.1. 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, 2 and 17 and Appendix A for demographic and additional behavioral and lesion data. Fig. 1 shows the approximate extent of his neocortical damage.

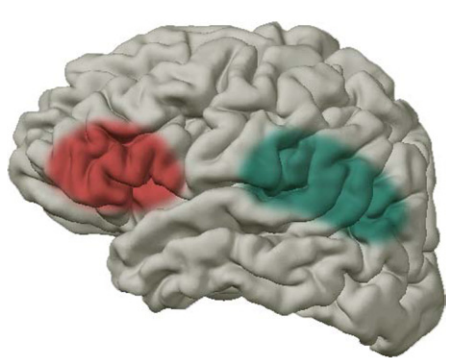

Fig. 1. Approximate extent of cortical damage to agrammatic non-fluent aphasic FCL and anomic fluent aphasic JLU.

FCL's scores were compared to those of a group of 12 age- and education-matched control subjects (see Section 4), 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 "lower fence" is used as a cutoff below which data 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 four real regular past tenses (*scowled*, *scoured*, *dropped*, and *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 controls' 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 five regularizations of novel irregulars (*crived*, *trined*, *preeded*, *cleeded*, and *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 no significant difference between the two verb types, and actually performed slightly better at regulars than irregulars (98% vs. 96%; $t(11) = 0.96$, $p = .358$, over subjects; $t(34) = 1.00$, $p = .326$, over items). FCL was also much 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 difference (96% vs. 95%; paired $t(11) = .583$, $p = .571$, over subjects). In contrast to FCL's worse performance at both real and novel regulars as compared to irregulars, his production rates of real and novel regulars (e.g., *walked* vs. *plagged*) were *not* statistically significantly different from each other ($t(38) = 1.44$, $p = .159$). He produced no over-regularizations (*digged*), despite ample opportunity to do so, given that 31% of his irregular items yielded

Table 5
Responses in past tense production task: Non-fluent and fluent aphasics

Verb type		FCL	RBA	Control subjects (Non-fluent aphasics)	JLU	HFL, JHA, JMO, WBO, and APE	Control subjects (fluent aphasics)
n		1	1	12	1	5	8
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)

Table 5 (*continued*)

Verb type		FCL	RBA	Control subjects (Non-fluent aphasics)	JLU	HFL, JHA, JMO, WBO, and APE	Control subjects (fluent aphasics)
n		1	1	12	1	5	8
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

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

errors. In contrast, the control subjects did generate over-regularizations (0.5% of items, 14% of errors), despite the small number incorrect irregulars (4% of items).

FCL's difficulties at producing regular 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, irregular past tense forms would be easier to retrieve. 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 phonologically complex, or 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*). Such differences in phonological complexity could plausibly explain FCL's deficit at regulars from the perspective of the Joanisse and Seidenberg model—that is, FCL might be treated as an exceptional outlier, even though their simulations did not reliably yield a regular deficit (see discussion above). Additionally, it could be argued that the articulatory impairments typically found in Broca's aphasics (Alexander, 1997; Goodglass, 1993) might lead to more errors producing the more complex regular 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 articulatory or phonological complexity accounts. First, there were no phonological simplification errors among the irregulars: FCL never produced forms like *keep–kep*, *bend–ben*, or *send–sen*, as would be expected on both accounts. Second, FCL's production of unmarked irregulars (*keep*) can not easily be explained by either account. To further test the two accounts, we analyzed a subset of the regular items, excluding those regulars 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*). Importantly, the resulting group of 10 regulars (*scowl*, *flush*, *cram*, *mar*, *scour*, *slam*, *cross*, *rush*, *stir*, and *soar*) yielded only three correct responses (30% vs. the 69% correct on irregulars; independent $t(24) = 2.00$, $p = .057$). Together, the three analyses argue against both the articulatory and phonological complexity explanations.

The results presented above indicate that FCL was impaired at producing -*ed*-suffixed forms, of both real and novel regulars and in over-regularizations, but was relatively spared at producing irregular past tense forms. Moreover, this dissociation is not obviously accounted for by frequency, phonological or articulatory differences between the regular and irregular test items. These data appear to be best explained by an impairment of -*ed*-suffixation and a relative sparing of 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. Just like every day, yesterday I ____ → "*ran* after Albert"). FeCL made five such errors: *rush–ran*, *drite–swam*, *frink–fret*, *shrell–squeeze*, and *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*, and *strut*). Thus even among substituted forms, irregular past tenses were more successfully produced than regular past tense forms.

5.2.1.2. A non-fluent aphasic with a less circumscribed lesion: RBA. Non-fluent aphasics with less circumscribed lesions, extending 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. Non-fluent aphasic RBA had such a lesion. See Tables 1, 2, and 17 and Appendix A for demographic, behavioral, and lesion data.

RBA was severely impaired at producing regular past tense forms (Table 5). 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 controls' lower fence. He was slightly worse at producing regulars than irregulars. However, 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). RBA 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 revealed by his response times. Response times 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 ____") up to 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 s vs. 1.75 s; independent $t(6) = 2.06$, $p = .086$). Note that because we predicted greater difficulty with regular than irregular forms, it is justifiable to report p as one-tailed ($p = .043$). The same pattern held when the verbs' past tense frequencies were co-varied out, in which case the regular/irregular reaction time differences were 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. Importantly, he performed similarly in a sentence-picture matching task that probed 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. On passive sentences, which may require greater syntactic resources than active sentences (e.g., Kolk, 1998; Zurif, 1995), he consistently asked for the sentence to be repeated. On these sentences he also pointed 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 (Edgar 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. This pattern suggests a broad grammatical deficit, consistent with a dual-system view.

5.2.2. Fluent aphasia

The past tense production task was given to six fluent aphasic subjects: JLU, HFL, JHA, JMO, WBO, and APE (Tables 5–7). 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, sparing frontal and basal-ganglia structures. Fig. 1 shows the approximate extent of his cortical damage. The other five patients had less circumscribed lesions, which extended to frontal areas and/or the basal ganglia. See Tables 1, 2, and 17 and Appendix A for demographic, behavioral, and lesion data.

5.2.2.1. A fluent aphasic with a circumscribed posterior lesion: JLU. JLU was severely impaired at producing real and novel irregulars, but was relatively spared at the production of *-ed*-suffixed forms (Table 5). 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 than their *mean* score. 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.

Table 6
Responses in past tense production task: The five fluent aphasics with less circumscribed lesions

Verb type		HFL	JHA	JMO	WBO	APE	Mean	Control subjects
n		1	1	1	1	1	5	8
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)

(*continued on next page*)

Table 6 (*continued*)

Verb type		HFL	JHA	JMO	WBO	APE	Mean	Control subjects
n		1	1	1	1	1	5	8
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

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

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 error pattern was also suggestive. Of his six errors on irregular items, three were over-regularizations (*clinged*, *wringed*, and *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*, and *scash–scatched*). These included two -*ed*-suffixed distortions (*probbed*, *scatched*), which could not have been memorized because they are not existing words. 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 score (see Appendix A). These data, in particular the concomitant deficits on real and novel irregulars, do not appear to be consistent with the Joanisse and Seidenberg model. Rather, the findings suggest an impairment of memory-based real and novel irregulars and other lexical forms, and a relative sparing of the use of -*ed*-suffixation and other grammatical rules.

5.2.2.2. Five fluent aphasics with less circumscribed lesions
We replicated JLU's pattern with a larger sample of five fluent aphasics with less circumscribed lesions: patients HFL, JHA, JMO, WBO, and APE (Tables 5 and 6). 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.

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 aphasics had significantly greater difficulty producing irregular than regular past tenses (Table 5; paired $t(4) = 6.19$, $p = .003$, over subjects; independent $t(34) = 2.00$, $p = .053$, over items). In contrast, the control subjects' rates on irregular and regular verbs did not differ (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 regular deficit (Table 6). The regular/irregular difference for two subjects was 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 in fact produced none at all (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 (Table 5), they produced irregularizations at lower rate than

Table 7
Responses in the past tense production task: By item

	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)

(*continued on next page*)

Table 7 (*continued*)

	Non-fluent aphasics	Controls (non-fluent aphasics)	Fluent aphasics	Controls (Fluent aphasics)
n	2	12	6	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

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 five aphasics because JHA could not perform the task for novel verbs.

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 statistically 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.

The aphasics' production rate of regularizations of the same novel irregular verbs (e.g., *crive–crived*) did not differ reliably from that of the control subjects (53% vs. 64%) with subjects as the error term (independent $t(10) = 0.95$, $p = .367$), although, contrary to our expectations, this difference was nearly significant 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%). However, the aphasics also produced a large number of -*ed*-suffixed errors on novel irregulars, including -*ed*-suffixed distortions (*trine–drined*), syllabically suffixed forms (*blide–blide–id*), and multiply-suffixed forms (*sheel–sheeleded*) (Tables 5 and 6). The combination of these errors *and* the correctly -*ed*-suffixed stems (*crived*) yielded production rates of all suffixed novel irregular forms. These constituted 61% of responses on novel irregulars for the four aphasics able to perform the task for novel verbs. 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 of novel irregular verbs, but produced a similar number of -*ed*-suffixed forms as their control subjects on the same verbs.

These findings show that, even in the fluent aphasics with less circumscribed lesions, the production of real and novel irregulars was more impaired than 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.

5.2.3. 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 (Table 5, Fig. 2). 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 ($F(1,34) = 1.48$, $p = .233$). The ANOVA between Non-Fluent/Fluent Aphasia and Novel Regular/Real Irregular Verb (e.g., *plagged* vs. *dug*) also yielded a significant interaction ($F(1,34) = 15.73$, $p < .0005$) and a significant main effect for patient group ($F(1,34) = 11.26$, $p < .002$), as well as a significant main effect for verb type ($F(1,34) = 6.47$, $p = .016$) (see Fig. 3 and 4).

The significant interactions further strengthen the hypothesis that past tense -*ed*-suffixation depends more on left anterior than left posterior structures, whereas irregular past tense formation depends more on 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 is largely spared in fluent aphasia. This hypothesis 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 complete it. 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*). If irregular inflection involves access to two stored forms (stem and past tense), whereas regu-

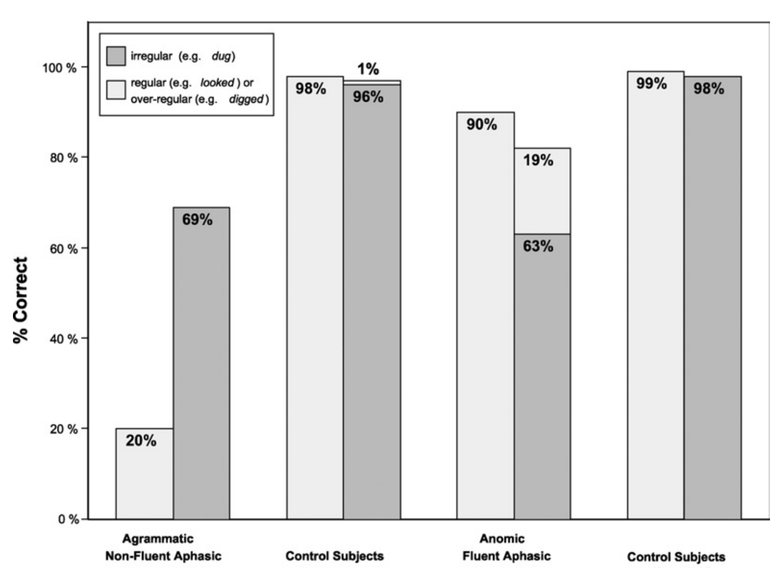

Fig. 2. Performance on the past tense production task by agrammatic non-fluent aphasic FCL, anomic fluent aphasic JLU, and control subjects.

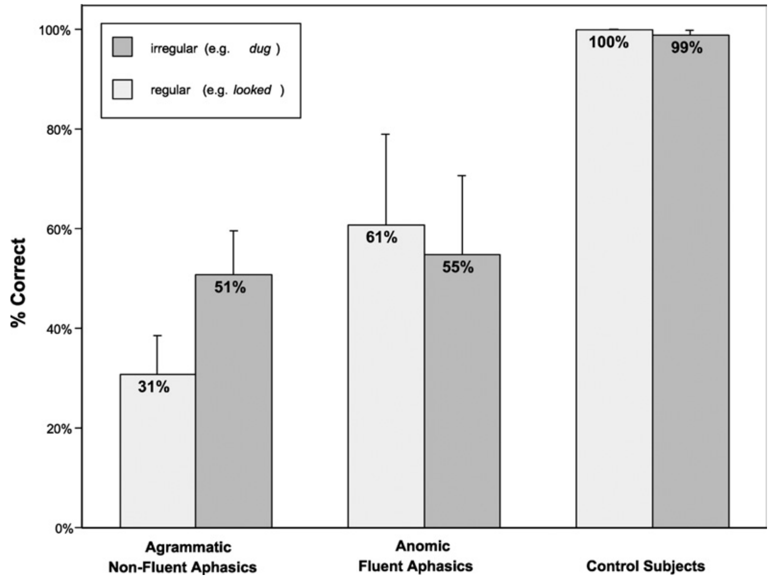

Fig. 3. Mean performance (with standard errors) on the past tense reading task by agrammatic non-fluent aphasics, anomic fluent aphasics, and control subjects.

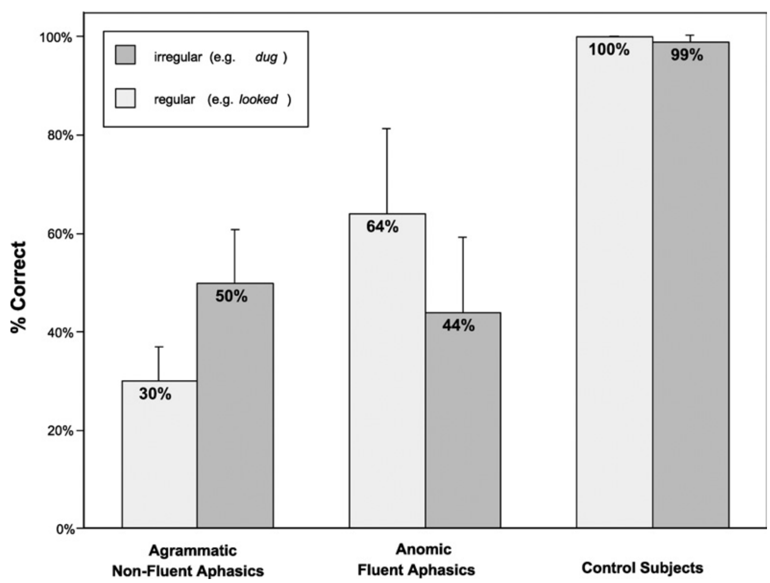

Fig. 4. Mean performance (with standard errors) on the past tense reading task, for the 9 regular and 9 irregular verbs matched for spelling-to-sound consistency, by agrammatic non-fluent aphasics, anomic fluent aphasics, and control subjects.

lar inflection need only involve one (stem), impairments of lexical memory (in fluent but *not* in non-fluent aphasia) that lead to distortions are more likely to be observed in the production of irregular than regular forms. The ANOVA between Non-Fluent/Fluent Aphasia and Regular/Irregular Verb Distortion yielded a nearly significant 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). Importantly, 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 did not show this difference, and in fact produced slightly more distortions for regulars (3% vs. 0%, for regulars and irregulars respectively; independent $t(35) = 1$, $p = .324$, over items). These data further strengthen the hypothesis that the production of irregular past tense forms depends on lexicalized phonological representations, which are impaired in fluent aphasia and relatively spared in non-fluent aphasia, whereas regular past tenses are computed by a distinct system that is impaired in non-fluent aphasia and relatively spared in fluent aphasia.

6. Study 2: Past tense reading

6.1. Method

6.1.1. Materials

Seventeen regular past tense forms were item-matched to 17 irregular past tense forms on phonological complexity (past tense syllable structure) and on the frequencies (Francis & Kucera, 1982) of their stem (unmarked) and past tense forms. The regular and irregular past tense forms did not differ statistically in the number of consonants in their initial consonant clusters (regular mean = 1.24, irregular mean = 1.59, paired $t(16) = 1.56$, $p = .138$) or their final consonant clusters (regular mean = 1.35, irregular mean = 1.47, paired $t(16) = 1.00$, $p = .332$). In fact, notice that in both cases the mean number of consonants was *higher* among the irregular than regular past tenses. Thus if non-fluent aphasics perform worse at regulars than irregulars, it cannot easily be attributed to a greater phonological complexity among the regulars (Bird et al., 2003; McClelland & Patterson, 2002). The regular and irregular items also did not differ 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: $t(16) = .44$, $p = .667$), again measured by paired t tests. See Table 8 for a list of the items and their mean frequencies.

6.1.2. Procedure

Each subject was tested individually, and received the 34 past tense items in a 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.

6.2. Results and discussion

6.2.1. 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 nine 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). Whereas the control subjects had similar scores at reading irregular (99%) and regular (100%) past tense forms, the aphasics were more accurate at reading irregulars than regulars (51% vs. 31%): 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 (Table 9). 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 ps reported as one-tailed (which is justifiable because we predicted the observed pattern). The remaining two subjects (NSL, HTA) did not differ statistically in their ability to read regular versus irregular past tense forms: both subjects showed the same pattern (29% vs. 24% correct, paired $t(16) = 0.37$, $p = .718$).

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*; cf. *mint*, *lint*, *dint*, etc.) can be more difficult to read than words with more "consistent" mappings, such as *kick* (cf. *lick*, *stick*, *flick*, etc.) (Coltheart et al., 1993; Plaut et al., 1996). Thus any difference between the regular and irregular past tense items in orthography-to-phonology consistency might plausibly 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 *in*consistency 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. These groups consisted of nine regulars (*slipped*, *tried*, *tied*, *died*, *sighed*, *weighed*, *learned*, *seemed*, and *stayed*) and nine irregulars (*swore*, *fled*, *clung*, *slid*, *bought*, *swept*, *kept*, *held*, and *drove*). Both groups had an average of 10.9 neighboring friends. Similarly, the regulars had an average of 0.33 enemies and the irregulars

Table 8
Regular and irregular verbs in the past tense reading task

Verb stem	Stem frequency FK	Stem frequency AP	Past tense	Past tense frequency FK	Past tense frequency 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

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.

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 nine 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). In sum, 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.

Table 9
Responses in past tense reading task: Non-fluent aphasics

Verb type		FCL	CIG	WRO	LDO	PJ	KCL	NSL	HTA	NWH	Mean	Control subjects
n		1	1	1	1	1	1	1	1	1	9	8
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

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.

It might be argued that the non-fluent aphasics' particular impairment at reading regular past tenses could be explained by a tendency to stop reading when a full word is encountered. In this case, 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 correctly. 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; see Table 9) 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*, and *country*. Their ln-transformed frequencies did not differ statistically 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 quite revealing. None of the patients 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 as compared with irregulars, either 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) or 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 (NSL, KCL, 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, especially for regular 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 a morpho-syntactic impairment in addition to the posited morpho-phonological suffixation impairment (independent of whether or not the two impairments have a common basis), and that syntactic processing is invoked during the processing of inflected forms, even when those forms are presented in isolation (i.e., not in syntactic contexts)—since in this case, the morpho-syntactic deficit would be expected to lead to greater difficulty computing tensed than unmarked forms, while the morpho-phonological deficit leads to additional difficulty computing regulars (Izvorski & Ullman, 1999; Pancheva & Ullman, under revision).

These reading data show that non-fluent aphasics have more trouble reading regular than irregular past tense forms, even when controlling for word frequency, phonological complexity, 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 findings. 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.

6.2.2. Fluent aphasia

The past tense reading task was given to five fluent aphasic subjects: LBR, YHY, RHH, HFL, and APE (Tables 11 and 12). As expected, these aphasics had higher scores at reading regular than irregular past tenses (61% vs. 55%), 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 (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: $p = .332$,

Table 10
Responses in stem reading task: Non-fluent aphasics

Verb type		NSL	KCL	HTA	NWH	Mean
n		1	1	1	1	4
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)

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

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 no interaction was evident with items as the error term ($F(1,32) = .64$, $p = .430$).

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 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, which could lower the fluent aphasics' performance at reading regulars, thereby diminishing the predicted relative disadvantage of irregulars. We therefore examined 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

Table 11
Responses in past tense reading task: Fluent aphasics

Verb type		LBR	YHY	RHH	HFL	APE	Mean	Control subjects
n		1	1	1	1	1	5	8
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

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

performance reading regular than irregular items (APE: 100% vs. 78%; $p = .085$; HFL: 89% vs. 44%; $p = .018$; LBR: 22% vs. 0%; $p = .085$; and YHY: 89% vs. 78%; $p = .174$), as measured by paired t tests over items, with ps reported as one-tailed. One aphasic showed no difference at all (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 irregulars 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 is consistent with the view that in fluent aphasia,

Table 12
Responses in the past tense reading task: By item

	Non-fluent aphasics	Fluent aphasics	Control subjects
n	9	5	8
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

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.

unlike in non-fluent aphasia, the syntactic mechanisms underlying the computation of tense are largely spared.

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

6.2.3. Non-fluent vs. fluent aphasics

We also 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), and 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 particularly impairs regulars, which are linked to left anterior regions, whereas fluent aphasia especially impairs irregulars, which are linked to left posterior regions.

The non-fluent and fluent aphasics' pattern of errors was also suggestive. 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). Moreover, we reported above that the fluent aphasics produced significantly more distortions for reading irregulars than for regulars, whereas the non-fluent aphasics did not show this pattern. These results largely replicate the pattern of distortion errors in the past tense production task, underscoring the greater dependence of irregular past tense forms on a posterior temporal/temporo-parietal lexical memory.

7. Study 3: Past tense judgment

7.1. Method

7.1.1. 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 additionally 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*, and *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 about the doublet verbs.

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

Table 13
Responses in stem reading task: Fluent aphasics

Verb type		LBR	RHH	YHY	Mean
n		1	1	1	3
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)

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

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 form (*dived*) and doublet irregular form (*dove*).

7.1.2. 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. For testing and coding convenience, all subjects received items in the same order. Subjects were tested individually. They were initially given several practice items. Control subjects read each sentence pair out loud; an experimenter read them aloud to the aphasic patients. Each sentence pair was

Table 14
Responses in the stem reading task: By item

	Non-fluent aphasics	Fluent aphasics
n	4	3
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

Percent correct responses (and number of subjects who produced a correct response in parentheses).

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. 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 in the second sentence (the past tense sentence) 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. 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.

7.2. Results and discussion

The past tense judgment task was given to three agrammatic non-fluent aphasics and one anomic fluent aphasic. Each subject's data were analyzed separately.

7.2.1. Non-fluent aphasia

7.2.1.1. An non-fluent aphasic with a circumscribed anterior lesion: FCL. The 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 *-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). As predicted, FCL gave higher ratings for irregular than regular past tense forms, (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 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 may be explained by the control subjects' wider rating scale (1–10), which could lead to fewer selections of perfect ratings than the smaller rating scale used by FCL (1–5). 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 control subjects' pattern of higher ratings for regulars than irregulars makes it "harder" to demonstrate the opposite pattern in non-fluent aphasics. Even if non-fluent aphasia were to affect only regulars, leaving irregulars intact, leading to a deficit of regulars but not irregulars as compared to control subjects, the aphasics' ratings for regulars might still be no lower, or not significantly lower, than their ratings for irregulars. By analogy, a disease that stunts the growth of redwoods but not of dogwoods is still unlikely to lead to shorter redwoods than dogwoods. Thus FCL's significantly lower ratings for regulars than irregulars suggests a substantial dysfunction on regulars.

Table 15
Doublet verbs in the past tense judgment task

Verb Stem	Stem frequency FK	Stem frequency AP	Regular past tense form	Regular past tense frequency FK	Regular past tense frequency AP	Irregular past tense form	Irregular past tense frequency FK	Irregular past tense frequency 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	

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.

It might be argued that FCL's lower ratings on regulars than irregulars 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 seems unlikely, since the control subjects showed the opposite pattern, with better performance on regulars than irregulars. Nevertheless, we 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 regular advantage, 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*) did not differ significantly from his ratings either 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's ratings on incorrect forms were also consistent with grammatical difficulties. He gave similar ratings as his controls to over-regularizations (*digged*) (25 vs. 26; paired $t(15) = 1.0$, $p = .925$, over items). Intriguingly, 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 hesitations. This pattern is compatible both with intact blocking by irregular past tense forms, and with difficulty computing the *-ed*-suffixed over-regularizations. FCL also failed to reject (i.e., did not give the lowest rating to) 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 seems consistent with both a morphological failure to compute *-ed*-suffixation, and a morphosyntactic impairment.

In summary, FCL gave lower ratings to regular than irregular past tense forms, and appeared to have trouble with *-ed*-suffixed novel forms and over-regularizations. These results are consistent with the hypothesis that, even in past tense judgment, *-ed*-suffixed forms were more difficult for him to compute than irregulars. 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 irregulars.

7.2.1.2. Two non-fluent aphasics with less circumscribed lesions. Non-fluent aphasics with less circumscribed lesions, involving not only left frontal but also 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 $t(21) = 1.25$, $p = .133$, 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 a trend in the opposite direction, with higher ratings for irregulars than regulars (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's ratings on incorrect forms were also revealing. He gave ratings to 8 over-regularizations. These ratings 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; $t(9)=4.13$, $p=.003$), as well as 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 ratings 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, and that the controls showed the opposite pattern (over-regularizations 26 vs. unmarked forms 15; independent $t(34)=6.15$, $p<0.001$). Importantly, his high ratings on the 10 unmarked regular verb-forms also show that the 8 regular past tense forms' non-significant difference from zero cannot be simply attributed to their small sample size. BMC was unable to carry out the task for novel verb forms, and thus no analyses on these verbs were performed.

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 response times were acquired during testing, with an experimenter counting 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) regular than irregular past tense forms (1.8 s vs. 0.6 s; 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).

RBA's 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; see above), RBA did not show such a significant difference (34 vs. 23; independent $t(34)=0.82$, $p=0.418$). In addition, RBA showed a tendency to be slower at rating unmarked forms than over-regularizations (4.3 s vs. 2.9 s; independent $t(34)=1.445$, $p=0.158$). Finally, his ratings for unmarked forms were significantly greater than zero (mean of 23, $t(19)=2.49$, $p=0.022$). Like BMC, RBA was unable to carry out the task for novel verb forms.

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 it in longer reaction times for regulars. Both subjects gave 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 possibly of morphosyntactic impairments as well, while knowledge of irregulars is largely maintained.

7.2.2. Fluent aphasia

The hypothesized lexical impairments of fluent aphasics should lead to more trouble recognizing correct real and novel irregular forms (e.g., *dug*, *dove*, and *crove*) than real and novel regular forms (e.g., *walked*, *dived*, *plagged*, and *crived*), and to the acceptance of over-regularizations (e.g., *digged*). Moreover, because these patients are posited to have intact morphological rule-processing, and presumably intact morpho-syntax as well, they should correctly reject unmarked forms of real and novel regulars (*walk*, *plag*).

7.2.2.1. 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 post-onset. By this point his aphasia had 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, his performance had clearly improved (75% correct irregulars vs. 95% correct regulars). Similarly, his performance was excellent at the judgment task, and indeed was at ceiling, with mean ratings of 100 for irregulars as well as regulars.

We therefore examined his judgment of doublet verbs (e.g., *dive–dove/dived*). The irregular past tense frequencies of these items are substantially lower than those of the other irregular items (see Tables 3 and 15), so JLU should be less likely to reach ceiling when judging the doublet irregulars (*dove*). In unimpaired control subjects, doublet regulars (*dived*) are predicted to be stored (see above). 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 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 $t(30) = 5.04$, $p < .001$). 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 the 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 $t(30) = 0.41$, $p = .687$; BMC: 0 vs. 50 for the two doublet regulars and two doublet irregulars to which he gave ratings; RBA: 94 vs. 83, independent $t(30) = 1.04$, $p = .306$).

JLU's pattern of lower ratings on doublet irregular than doublet regular 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 similar ratings (66 vs. 72; paired $t(17) = 1.69$, $p = .109$). Moreover, 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 the 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 the controls' ratings (100 vs. 85, paired $t(17) = 25.59$, $p < .0001$).

As with the non-fluent aphasics, JLU's ratings of incorrect forms were also revealing. 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. In contrast, JLU gave ratings of 0 to all 20 unmarked forms of regular verbs (e.g., *walk*), and to all 20 unmarked forms of novel regular verbs (e.g., *plag*). 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 morpho-syntactic processing, both which are relatively spared in fluent aphasia.

7.2.3. 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 real and novel irregular forms depends more upon left temporal/temporo-parietal regions, whereas the computation of *-ed*-suffixed forms depends particularly upon left frontal structures.

8. Regular and irregular morphology: Previous evidence

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. As summarized briefly in Section 1, there have been a number of other studies examining aphasics' use of English regular/irregular inflection. Several recent studies have focused specifically on the regular/irregular distinction (Bird et al., 2003; Marslen-Wilson & Tyler, 1997; Miozzo, 2003; Tyler, de Mornay-Davies, et al., 2002; Ullman, Corkin, et al., 1997). These have received extensive attention (e.g., McClelland & Patterson, 2002; Pinker & Ullman, 2002), and so will not be presented in detail here. However, a number of other examinations of regular/irregular inflection in aphasic patients can be found in older reports which did not focus on this inflectional distinction in particular. These studies investigated the reading, writing or repetition of real regular and irregular English past tense or plural forms in patients with the left frontal patients. In each case the patient was less successful with regular than irregular forms. Here we provide an overview of the findings (with additional analyses in some cases), together with supplementary behavioral and lesion data, including from other studies of the same patients (also see Table 16).

Patients HT and VS. Both patients suffered left middle cerebral artery strokes. CT scans revealed the following (Coltheart et al., 1980): In both individuals, classical Broca's area was involved, although in VS the damage was probably partial, and 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 also showed superior temporal sub-cortical damage, but only VS had superior temporal cortical damage. In each case 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.

HT and VS were both "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).

Table 16
Aphasic subjects from previous studies of regular and irregular processing: demographic data

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

Note. Age is calculated at the date of testing regular and irregular inflection.

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 the greater phonological complexity or articulatory difficulty of regulars, 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 as compared to 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 that this unaffixed/affixed difference was no longer apparent (Coslett, 1988). She named 87% of the items in the Boston Naming Test (Goodglass, Kaplan, & Weintraub, 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* seems unlikely to be explained by phonological or articulatory impairments. Her near-perfect performance at writing irregulars, in comparison to her severely impaired performance at writing regulars, suggests damage to neural structures that subserve the writing of plural and past tense regulars, but have 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 and do not rely on morpho-phonological composition.

Patient SJD. SJD suffered a stroke in the region of the left middle cerebral artery. A CT scan 1 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 both 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). Thus her deficit at regulars does not appear to be explained solely by differences in phonological complexity or articulatory difficulty. 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 correctly read more monomorphemic embedded words than suffixed words (86% vs. 79%), although the difference was not statistically significant. On the suffixed words she primarily produced morphological deletions and substitutions (19% of items, 89% of errors); she made fewer analogous errors for the embedded words (6% of items, 50% of errors): $\chi^2(1) = 3.76$, $p = .053$. Importantly, none of her errors on embedded words 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. Similar to 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 inflected forms, but are not necessary for the reading of irregulars. This suggests that morpho-phonological and morpho-syntactic computations may depend upon at least partially distinct neurocognitive components. This view is strengthened by the finding that SJD was no worse at reading irregular than uninflected forms.

Patient FM. FM suffered a stroke of the left middle cerebral artery. A CT scan 2 years post-onset showed a large area of lucency involving the posterior inferior frontal lobe, the inferior parietal lobe, the anterior temporal lobe, the underlying white matter, and the lateral basal ganglia (Badecker & Caramazza, 1987). The authors reported that FM's speech was "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 4 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. In a separate task, the same 150 words were read out loud, with FM being 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, as well as to read 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. Finally, when FM was also asked to read 21 irregular past tense forms and 41 regular past tense forms, he read more irregular than regular forms correctly (38% vs. 17%).

Summary. All seven patients from these previously reported studies had left frontal lesions and greater deficits at 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 passive or active sentences, phonological dyslexia, and more trouble producing or reading verbs than nouns. Crucially, all seven patients were worse at reading, writing or orally repeating regular than irregular past tense or plural forms. Moreover the evidence suggests that phonological complexity, articulatory, frequency, letter length, and initial substring explanations do not account for the regular–irregular dissociations in one or more patients.

9. General discussion

The three new studies reported here yielded double dissociations between regular and irregular inflectional morphology. Non-fluent agrammatic aphasics with left frontal damage were more impaired at producing, reading, or judging, real regular than real irregular past tense forms. In contrast, fluent anomic aphasics with temporal/temporo-parietal damage were more impaired at producing, reading, and judging irregular than regular past tense forms. The dissociations held even when measures of a number of potential confounding factors were held constant between regular and irregular items: stem and past tense frequency; past tense phonological complexity and articulatory difficulty; and consistency of spelling-to-sound mappings of past tense forms in the reading task. Initial substring explanations also do not appear to account for the data. Moreover, an analogous double dissociation was found for new and novel verb forms. The non-fluent aphasics produced virtually no over-regularizations and had difficulty producing and judging -*ed*-suffixed novel verb forms (e.g., *plagged*, *crived*). In contrast, the fluent aphasics produced and accepted 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 non-fluent aphasics examined, both patients who performed the production task showed the deficit of regulars, 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 small and non-significant advantage at reading irregulars over regulars (in both cases, 29% vs. 24%, $p > .7$).

Of the fluent aphasics examined, all six patients tested 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%).

The data from this study are predicted by a dual system view in which affixation and irregularization in English inflectional morpho-phonology are subserved by distinct neurocognitive systems, with affixation depending largely on left frontal structures, and the use of real and novel irregulars on left temporal/temporo-parietal regions. Moreover, the evidence from both types of aphasics suggests strong links between regular morphology and syntax on the one hand, and irregular morphology and lexical memory on the other, indicating that the two systems play larger roles within grammar and lexicon, respectively: first, the non-fluent aphasics had difficulty with aspects of syntax as well as regular past tense forms. All had agrammatic speech, as defined by a reduction of phrase length and grammatical complexity. All those tested on syntactic comprehension tasks were impaired on these tasks, indicating that these patients suffered from receptive agrammatism as well. In addition, 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 nine patients had word-finding difficulties (anomia), in spontaneous speech and/or in picture naming. Moreover, in both the production and reading tasks, the fluent (but not non-fluent) aphasics produced more distortions on irregular than regular verbs, suggesting that the fluent (but not non-fluent) aphasics suffered damage to brain structures which subserve the sound patterns of stored words, and that the use of irregulars but not of regulars is particularly dependent upon these structures.

The findings from these studies are not easily explained by any previously reported single-mechanism models, including that proposed by Joanisse and Seidenberg (1999). As discussed above, their model does not predicted reliable deficits of regular inflection, in particular when phonological complexity and frequency are taken into account. Crucially, the regular deficits observed in the non-fluent aphasics reported here survived when measures of these and other factors were fully or largely accounted for. Moreover, even when the regular and irregular items were not matched on these factors, in a number of analyses in Studies 1 and 3, it is not clear that Joanisse and Seidenberg would expect regular deficits, since their simulations based on the *same* items did *not* yield a regular deficit. As discussed above, other results obtained in these studies also appear to be problematic for this connectionist model: First, the finding that the non-fluent aphasics did not produce errors like *kep* in lieu of *kept* does not appear to be consistent with the phonological impairments assumed by the model (Bird et al., 2003; Joanisse & Seidenberg, 1999). Second, it is not clear how such phonological impairments would lead to these aphasics' concomitant syntactic impairments, which were found in both expressive and receptive language. Third, while the semantic deficits posited by their model for the fluent aphasics may explain these patients' impairments with real irregular forms, they do not in any obvious way predict their deficits with novel irregularizations (e.g., *crove*), in either the production or judgment tasks (see above, and Pinker & Ullman, 2002).

The data from studies are also relevant to the theory of Distributed Morphology (Halle & Marantz, 1993). This theory takes the position 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* + Z; *dig* → *dug* + Z). 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 nine 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*-/θɔ/ (sounds like "thaw"), *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 on the *stem* reading task (patient KCL: *lend–len*, *send–sen*, *spend–spen*; NSL: *lend–len*), 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 morpho-phonological affixation.

9.1. Localization

The lesion data reported for the patients in the three studies elucidate the neuroanatomical localization of the linguistic functions of interest. All 11 of the non-fluent aphasics that we tested had damage to left frontal regions (see Table 17 and Appendix A). This was the only region affected in all 11 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

Table 17
Aphasic subjects: Summary of lesioned brain structures

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, Wernicke's +
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	—	—	—	—	—

Note. All lesioned structures are in the left hemisphere. None of the subjects had any known right hemisphere damage. Legend: 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.

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.

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 may be explained by extensions of their lesions to temporal/parietal structures, which would be expected to impair irregulars. Because the only brain structure known to be damaged in all 11 subjects was left frontal cortex, this region is implicated in morphological affixation as well as aspects of syntax. 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 (judgment) tasks. More generally, the implication of these frontal regions, and Broca's area in particular, is consistent with the hypothesis that the "procedural memory" system, which is rooted in frontal/basal-ganglia structures and is implicated in motor and cognitive skills and habits, plays a role in the mental grammar (Ullman, 2001c, 2004, under review; Ullman, Corkin, et al., 1997).

The seven fluent aphasics with reported lesion data all had temporal and/or inferior parietal (i.e., temporo-parietal) lesions (see Table 17 and Appendix A). 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 had anomia and 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 word-finding difficulties and impaired irregular morphology was the broad temporal/temporo-parietal region. 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 the "declarative memory" system, which is rooted in temporal/temporo-parietal structures, and is implicated in the memory for conceptual knowledge, also subserves lexical memory, including the stored sound structures of words (Ullman, 2001c, 2004; Ullman, Corkin, et al., 1997).

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 play an important role in the mental grammar or the mental lexicon. Nor do they obviate the possibility that certain temporal-lobe regions may subserve grammatical functions, especially other than morphological affixation and the syntactic licensing of inflection. Finally, they are not inconsistent with the claim that left frontal structures also play some sort of role in the search, selection or retrieval of lexical and semantic information (Ullman, 2004, under review).

10. 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 use 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 irregular than regular past tense forms, in production, reading, and judgment tasks. The remaining fluent aphasic showed no difference between regular and irregular forms. These double dissociations were maintained even when measures of a variety of other factors, including frequency, phonological complexity, 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 with 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). Aspects of the data also seem to pose a challenge for Distributed Morphology (Halle & Marantz, 1993). The results support a dual-system model in which the computation of affixed and irregularized inflected forms depend upon distinct neural underpinnings. The association of non-fluent aphasia, left anterior lesions, agrammatism, apparent syntactic deficits in all 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 fluent aphasia, left posterior lesions, lexical difficulties, and impairments of real and novel 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, encompasses irregularly inflected as well as uninflected words, and subserves the use of novel irregularizations. An examination of the tested aphasics' lesioned structures implicates left temporal and/or temporo-parietal structures in these functions.

The results obtained in the present experiments, and in the older studies discussed in some detail, are largely consistent with data reported elsewhere. As summarized in Section 1, a number of recent studies have also found regular deficits in non-fluent aphasics, in production, reading, judgment, and priming tasks (Marslen-Wilson & Tyler, 1997; Tyler, de Mornay-Davies, et al., 2002), with the opposite pattern reported for production tasks given to fluent aphasics (Miozzo, 2003; Ullman, Corkin, et al., 1997). To our knowledge, only one study of aphasia has argued that their data do not support the existence of reliable regular/irregular dissociations in English inflectional morphology (Bird et al., 2003). This investigation examined 10 non-fluent agrammatic aphasics on production, repetition, reading, and judgment tasks. When phonological complexity, frequency, and other factors were accounted for, the regular deficit was weakened considerably. However, controlling for these other factors did not eliminate the effect completely. First, the regular impairment in the reading task survived in all analyses. Moreover, in the repetition task, only a post hoc analysis, in which irregular past tense forms that had inconsistent voicing (e.g., *felt*) were excluded, eliminated the regular disadvantage. Thus even in this study, whose primary theoretical motivation was to demonstrate that the regular deficit does not survive when phonological and other factors are controlled for, it was difficult to impossible to eliminate the effect.

In conclusion, we have presented a detailed analysis and discussion of the computation of English regular and irregular inflected forms in agrammatic non-fluent aphasia and anomic fluent aphasia. The findings from these studies support the view that language is a modular system—that is, language is subserved by separable neurocognitive components: at least certain aspects of the mental grammar, including 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 "declarative/procedural" hypothesis 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 (Ullman, 2001c, 2004; Ullman, Corkin, et al., 1997).

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Appendix A

Here we present detailed behavioral and lesion data for the non-fluent and fluent aphasics whose performance is discussed in the three studies presented above.

A.1. 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, as well as 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, 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 extensions 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 post-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 cortices, 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, Coslett, 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, Linebarger, Saffran, and Pate (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 fronto-parietal cortex, in the basal-ganglia region, and in 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 fronto-parietal 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, in the peri-ventricular 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.

A.2. Fluent aphasic subjects

JLU suffered a left hemisphere stroke in 1992, 9 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) 6 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 encompassed 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 a 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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