Deficits for Semantics and the Irregular Past Tense: A Causal Relationship?

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Abstract

■ The regular and irregular past tense has become a focus for recent debates about the structure of the language processing system, asking whether language functions are subserved by different neural and functional mechanisms or whether all processes can be accommodated within a single unified system. A critical claim of leading single mechanism accounts is that the relationship between an irregular stem and its past tense form is primarily semantic and not morphological in nature. This predicts an obligatory relationship between semantic performance and access to the irregular past tense, such that a semantic deficit necessarily leads to impairments on the irregulars. We tested this claim in a series of studies probing the comprehension and production of regular and irregular past tense forms in four semantic dementia patients, all of whom had profound semantic deficits. In two elicitation tasks and one auditory priming study, we found that three out of the four patients did not have a deficit for the irregular past tense, in spite of their semantic deficits. This argues against the view that the relationship between irregular past tense forms and their stems is primarily semantic, and more generally against the single system claim that morphological structure can be captured solely based on phonological and semantic relationships. ■

INTRODUCTION

English inflectional morphology has been at the heart of recent debates about the processes required to produce and comprehend language. These debates concern the issue of whether language functions are subserved by different neural and functional systems or whether all processes can be accommodated within a single, unified mechanism (Marslen-Wilson & Tyler, 1998; Pinker, 1991; Rumelhart & McClelland, 1986). The contrast between the irregular and regular forms of the English past tense has featured heavily in this debate because of the strong contrast these offer between a highly rule-like process—the regular past tense formed by adding the affix /-d/ to the verb stem (as in *jump/jumped*, *sigh/sighed*)—and the unpredictable and idiosyncratic irregular forms (as in *think/thought*, *make/made*) applying to a small minority of English verbs. The critical empirical question has been whether these linguistic contrasts map onto qualitative underlying differences in the way the two types of form are represented and processed.

Neuropsychological studies of patients who have selective deficits for either the regular or irregular past tense in English have provided an important new input to this debate (e.g., Tyler, de Mornay Davies, et al., 2002; Tyler, Randall, & Marslen-Wilson, 2002; Patterson, Lambon Ralph, Hodges, & McClelland, 2001; Marslen-Wilson & Tyler, 1997; Ullman et al., 1997). This dissociation has shown up in several different experimental contexts, including both priming and elicitation tasks. Overall, these studies show that nonfluent aphasic patients with damage to the left inferior frontal cortex have problems with regularly inflected past tense forms but have essentially normal performance on irregularly inflected forms. These patients have difficulty in producing regularly inflected words in elicitation tasks (Ullman et al., 1997), and they do not show the normal pattern of priming for the regulars in priming studies, although the irregulars prime (Tyler, Randall, et al., 2002). This reflects a general disruption of lexical access from regular inflected forms, which fail to show significant semantic priming effects for pairs like *jumped/leap*, although the uninflected stems (*jump/leap*) prime normally (Longworth, Marslen-Wilson, & Tyler, 2002).

In contrast to this pattern of effects showing selective deficits with the regulars, a different group of patients, typically with temporal lobe damage but with sparing of the left inferior frontal cortex, show the opposite pattern, with better performance on regulars compared with irregulars in elicitation and reading tasks (Tyler, Randall, et al., 2002; Patterson et al., 2001; Marslen-Wilson, & Tyler, 1997; 1998; Ullman et al., 1997). This latter group of patients almost always exhibits an accompanying semantic deficit, and a prime issue for the

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research reported here is to disentangle cause and effect in the relationship between problems with the irregulars and problems with semantics.

Dual mechanism accounts straightforwardly explain the past tense dissociation in terms of selective damage to distinct underlying systems, with some variation in the types of mechanism being proposed. Several authors (Pinker & Ullman, 2002; Ullman, 2001; Ullman et al., 1997; Prasada & Pinker, 1993; Pinker, 1991) claim that the regulars are processed by means of a specific rule-based system that adds and strips away inflectional affixes from their stems. In contrast, the irregulars are learned individually by rote and stored in a separate knowledge store. On this account, problems with the regulars stem from damage to the productive regular rule-based system, while deficits for the irregulars arise as a consequence of damage to the store of words in the mental lexicon, which leaves rule-based processes intact.

We have proposed a modified version of the dual route account, which places less emphasis on the regularity/irregularity distinction per se and more emphasis on the role of specialized morphophonological parsing processes, which allow the segmentation and identification of stems and affixes (Tyler, de Mornay Davies, et al., 2002; Tyler, Randall, et al., 2002; Marslen-Wilson & Tyler, 1998, 2003). These processes, which are associated with left hemisphere inferior frontal cortex, are required for the analysis of regularly inflected forms in English, with their stem + affix structure, but do not apply to English irregular past tenses that have no overt morphophonological structure. These irregular forms can be mapped more directly from phonology to meaning, supported by left temporal lobe structures (cf. Tyler, de Mornay Davies, et al., 2002; Tyler, Randall, et al., 2002).

The evidence for neuropsychological dissociation presents a much stronger challenge to single mechanism theories, requiring them to show how apparent dissociations in the effects of damage to the brain could nonetheless be explained within a single mechanism framework. The most systematic riposte along these lines has come from the model proposed by Joanisse and Seidenberg (1999), where a single set of hidden units learns the mappings among speech input, speech output, and semantics for sets of regular and irregular past tense forms and their stems. The critical property of the model is the differential reliance of the regulars and irregulars on the contribution of phonology and semantics. The mapping between stems and their regular past tense forms is more dependent on phonological similarities between a stem and its inflected form (e.g., *open/opened*), whereas the irregulars are more dependent on the semantic relationship between a stem and its past tense form, since the phonological relationship between them is less predictable (e.g., *think/thought*).

This leads to the prediction that relatively selective deficits for the regulars will be caused by a phonological impairment. This has a greater impact on the regulars because the mapping between a regular stem and its past tense form is primarily phonological. In contrast, deficits for the irregulars should be a by-product of damage to the semantic system. This has a disproportionate effect on the irregulars because the mapping between an irregular stem and its past tense form is more reliant upon semantic similarity. To test these predictions, Joanisse and Seidenberg (1999) lesioned the semantic layer of their network and found that it generated a greater deficit for the irregulars. Lesioning the phonological output layer, in contrast, produced a greater deficit for the regulars.

The critical empirical claim of this type of model, later adopted in modified form by McClelland and Patterson (2002) and Patterson et al. (2001), is the causal link it specifies between phonological factors and regular morphology on the one hand and semantic factors and irregular morphology on the other. In recent research into the first of these claims (Tyler, Randall, et al, 2002), we showed that this link did not hold for phonology. In the research reported here, we examine the prediction that deficits with the irregulars are caused by difficulties with semantics.

Semantics and the English Irregular Past Tense

There is no doubt that deficits in performance on semantic tasks following damage to the brain are closely associated with difficulties in either producing or comprehending English irregular past tense forms. In an early report of a past-tense dissociation (Marslen-Wilson & Tyler, 1997), we described a stroke patient (T. S.) with bilateral temporal damage who failed to show priming for either irregular/stem pairs (*gave/give*) or for semantically related pairs (*swan/goose*), although regular past tense priming (*jumped/jump*) was intact. In a second report (Marslen-Wilson & Tyler, 1998), the semantic dementia patient E. S., with a severe semantic deficit and bilateral temporal lobe damage, showed exactly the same pattern, also in a priming task.

Subsequent reports, primarily using elicitation tasks, have shown relatively selective irregular past tense deficits for larger groups of patients. Patterson et al. (2001) report greater problems in producing irregulars than regulars for a group of semantic dementia patients, with some evidence that the extent of the problem increases with the degree of semantic deficit. Tyler, de Mornay Davies, et al. (2002) report a similar result for a group of patients with bilateral temporal lobe damage and semantic deficits following herpes simplex encephalitis. Finally, while this was not directly tested, it is likely that similar patterns can be found among the groups of patients reported by Ullman et al. (1997).

This consistent pattern of co-occurrence of semantic deficits and problems with the irregulars naturally raises the question of the basis of this regularity. Potential answers to this are highly dependent on theory. In the context of the currently predominant single mechanism connectionist model (McClelland & Patterson, 2002; Joanisse & Seidenberg, 1999), this linkage is necessary and causal. The relationship between irregular past tense forms and their stems, as indicated above, is viewed as being primarily a semantic relationship, while the relationship between a regular form and its stem is not. We specifically tested this possibility in earlier research with healthy subjects, and found little evidence to support it. In two different types of experiment, comparing priming between irregular and stem pairs (*gave/give*), regular and stem pairs (*called/call*), and semantically related pairs (*cello/violin*), we found that regular and irregular pairs patterned together and were quite distinct from the semantic pairs.

A first study, Marslen-Wilson and Tyler (1998), used the delayed auditory priming task to separate out the effects of morphology and semantics. This is a task where semantic priming drops away sharply over time, but morphological priming does not. Healthy subjects were presented with single words for lexical decision, with an average of 12 items intervening between each prime word and its target. Over these long lags, regularly inflected past tense forms should prime because of their morphological relationship, but purely semantically related pairs should not. If irregularly inflected pairs share a semantic rather than morphological relationship, then they should also not prime. In fact, the results showed equally strong priming for both regular and irregular inflected past tense forms at long lags, but no semantic priming. We argue that this is because both types of past tense share a morphological relationship with their stems, with priming being based on the reactivation of the same shared stem morpheme.

This analysis was supported by the results of a second study looking at the electrophysiological correlates of priming in the normal brain (Marslen-Wilson et al., 2000). Event-related scalp potentials were measured while subjects were performing a cross-modal priming task, with auditory primes and visual targets, comparing regulars, irregulars, and semantically related pairs. All three conditions elicited the N400 effect that is typically observed in priming tasks. However, the regulars and irregulars, but not the semantically related pairs, also exhibited a significant left anterior negativity. This is a type of activation that is usually associated with linguistic processes. As in the behavioral study, the pattern of responses elicited by the irregulars is much more similar to the pattern elicited by the regulars than it is to the semantically related pairs and has the characteristics of a linguistic relationship rather than a predominantly semantic relationship.

If, as these results indicate, the relationship between an irregular form and its stem in the undamaged system is not primarily semantic in nature, then we have to look for an alternative account both for deficits with the irregulars and for the correlation of these deficits with semantic impairments. Where the irregulars are concerned, and given the assumption that the primary access process involves mapping onto stored lexical representations, it is uncontroversial to assume that deficits here will result from damage to the systems mediating these access processes (with possible further refinements depending on whether this is access for production, from a semantic or conceptual starting point, or access for comprehension, from a phonological or orthographic starting point).

Where the correlation with semantic impairments are concerned, there are two possibilities. One is that disruption of lexical access can itself produce problems in semantic tasks (and vice versa where lexical access is itself driven by semantics, as in elicitation tasks). The second is that damage to areas involved in semantic performance, especially those in the temporal lobes and associated structures, may be likely to co-occur or overlap with the kinds of damage that disrupt lexical access per se in its various forms.

What all of these possibilities have in common is the implication that semantic deficits and problems with the irregulars (and more generally problems in lexical access) can occur independently. There is already evidence to support the first half of this prediction—namely, that problems in accessing the irregulars can occur in patients who do not have a semantic deficit. Miozzo (2003) has recently reported an anomic patient (A. W.), who has no semantic deficit as measured on a variety of different tasks and yet has a marked impairment for irregularly inflected past tense forms in an elicitation task.

The research we report here is targeted at the other half of the prediction—that patients can have a semantic deficit, but without this impairing their performance with irregulars. To address this question, we tested four patients who had been diagnosed as having semantic dementia based upon the results of behavioral studies, neuropathology, and clinical assessment. On a variety of behavioral measures, these patients all had severe semantic deficits. We tested the patients on their ability to comprehend and produce the regular and irregular past tense, using elicitation and priming tasks. The results show, as predicted, that there is not an obligatory relationship between a semantic deficit and problems with the irregular past tense.

Patients: General Description, Background Tests, and Neuropathology

Semantic dementia is the term which is used to describe patients whose primary deficit is a progressive loss of semantic knowledge. Other aspects of language (e.g., syntax and phonology) tend to be relatively preserved, as are nonsemantic cognitive abilities (Hodges, Patterson, Oxbury, & Funnell, 1992; Snowden, Goulding, & Neary, 1989). This pattern of deficit is usually associated with focal degeneration of bilateral anterior temporal cortex (Snowden & Neary, 2002; Galton et al., 2001). Patients typically present with word-finding problems in the presence of fluent speech and preserved memory for daily and autobiographical events. The four patients described below were diagnosed based on their neuropathology and clinical and neuropsychological assessment by experienced clinical neurology groups as suffering from semantic dementia.

1. B. S., a right-handed man, was 67 years old when tested. He left school at 16. When he first presented, he had been experiencing a gradual decline in semantic memory for around 4 years. He initially complained of difficulties in recognizing the faces of acquaintances, but by the time of the study, he also experienced frequent word-finding difficulties. He was anomic in spontaneous speech, on word fluency tasks, and on picture naming, and his poor performance on a range of tasks showed him to have a severe semantic deficit. In contrast, he was well oriented in time and space and had intact visual–spatial skills, nonverbal reasoning abilities, and memory for recent events. His speech was fluent and syntactically well formed. He did not make phonological errors in spontaneous speech or picture naming. He had good verbal short-term memory as measured by digit span.[1]

2. E. K., a right-handed woman, was 60 years old when first tested. She left school when she was 15. When she was first assessed, her word-finding abilities had been progressively deteriorating over the previous 5 years. She was living alone and doing occasional cooking and cleaning jobs at the time of the study. She was severely anomic in spontaneous speech, word fluency tasks, and picture naming, and performed poorly on comprehension tests using words and pictures. In contrast, she was well oriented in time and place and she had normal episodic memory, visual spatial processing, and nonverbal reasoning. Her speech was fluent and syntactically well formed despite her anomia, and she did not make phonological errors in her spontaneous speech or picture naming. Her digit span was normal (Jefferies, Patterson, Jones, Bateman, & Lambon Ralph, submitted).

3. J. T., a right-handed man, was 66 years old at testing. He left school at 16. He was running a small farming business at the time of the study. He had been experiencing worsening word-finding difficulties for 4 years prior to testing. Although he was severely impaired on a range of tests of semantic memory, his visual–spatial skills, nonverbal reasoning abilities, and memory for recent events were largely intact. He did not make phonological errors in spontaneous speech or picture naming and his digit span was normal.[1]

4. K. B., a right-handed woman, was 64 years old when tested in the current series of studies. She has been described in detail by Snowden and Neary (2002). When first seen in the clinic, her family had noticed over the previous 3 years that she was experiencing word-finding difficulties and had problems recognizing people and objects although her language was fluent and grammatically correct and her numerical skills appeared to be intact. She was severely anomic in picture-naming tasks and showed a severe semantic deficit across a variety of tasks. She had good verbal short-term memory as measured by digit span tests. At the time of testing, she lived alone and was able to carry out the normal range of daily living tasks, with the exception of cooking.

We carried out a voxel-based morphometric analysis to obtain an estimate of the extent of neuronal loss in the patients. T1-weighted MR scans were obtained for both patients and controls and were processed in SPM99 software (Wellcome Institute of Cognitive Neurology, www.fil.ion.ucl.ac.uk). All images were spatially normalized and comparisons were carried out between each patient and a group of eight age-matched controls. The images were initially skull stripped and coregistered to the SPM T1 template utilizing the mutual information registration algorithm. They were then spatially normalized to Talairach and Tournoux's atlas with 12 parameter linear affine transformations and were finally smoothed with a 12-mm isotropic Gaussian filter. The voxelwise comparisons between patients and controls were carried out in the context of the general linear model (Friston et al., 1995) as implemented in SPM99. The results from these comparisons were subjected to conjunction analysis (Price & Friston, 1997), the results of which are presented (at $p < .001$ uncorrected) in Figure 1 (Stamatakis & Tyler, 2003).

Figure 1 shows the extent of abnormal tissue in both the left and right temporal cortices, which is consistent with lesions generally reported for semantic dementia patients (Snowden & Neary, 2002; Galton et al., 2001). The damage was more substantial on the left (2478 voxels) than on the right (2118 voxels). In both hemispheres, the damage extends inferiorly from the temporal pole and fusiform gyrus to the superior temporal gyrus. In the left hemisphere, there was more extensive ventricular enlargement than in the right, and in the right hemisphere, there was damage to parahippocampal regions. Figure 1 also includes representative slices from each patient, showing that they all have a degree of bilateral anterior temporal damage.

The four patients were tested on a variety of tests designed to assess their cognitive and language abilities. Not all patients could be tested on all the tests. To assess their general cognitive abilities, we used Ravens Matrices, the Mini-Mental State Examination (MMSE), or the Addenbrooke's Cognitive Examination (ACE) (Mathuranath, Nestor, Berrios, Rakowicz, & Hodges, 2000). The ACE consists of a number of subtests that evaluate attention, memory, verbal fluency, language,

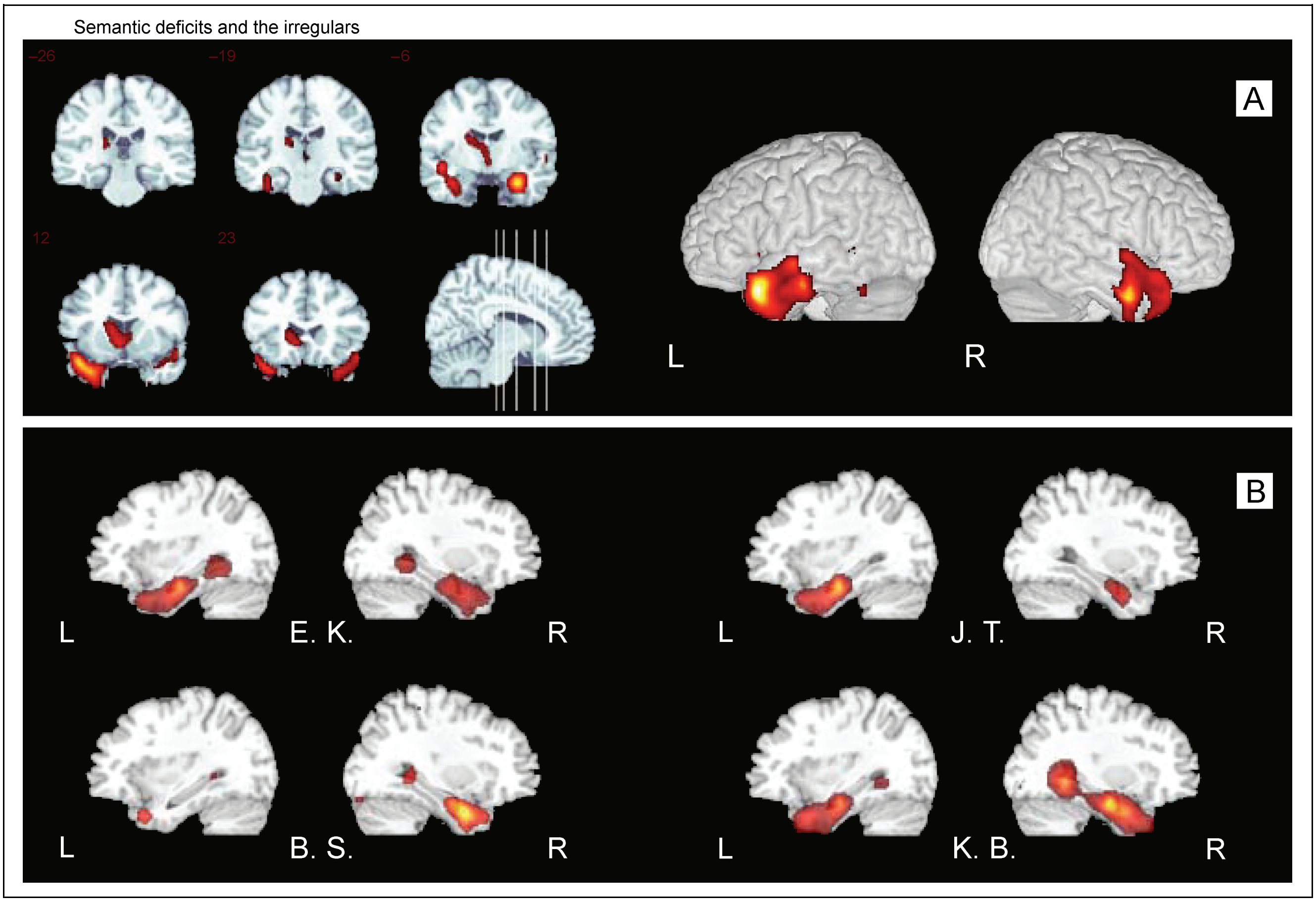


Figure 1. (A) Result of a conjunction analysis showing regions of significant difference between patients and controls. The regions are superimposed on a normal T1 image displayed in neurological convention (R is Right) and the values on the coronal slices represent Talairach y coordinates. (B) Regions of significant difference between individual patients and controls. Sagittal slices are shown at Talairach $x = -32$ (L) and $x = 32$ (R) for each patient.

and visuospatial skills. It is designed to provide an estimate of the degree to which a patient is cognitively impaired to be able to differentiate between patients with fronto-temporal dementia (AD; these patients have language deficits in the presence of generally preserved cognitive abilities) and patients suffering from Alzheimer's dementia (who have more general cognitive deficits). A score of less than 2.2 indicates fronto-temporal dementia and a score of greater than 3.2 indicates AD.

We also tested the patients on a variety of language tests, examining their phonology, syntax, semantics, and naming (see Table 1). The patients were clearly severely impaired on picture naming (Test 1) and they showed a pattern of surface dyslexia (Test 10) consistent with previous descriptions of semantic dementia patients (Snowden & Neary, 2002; Galton et al., 2001). To test the patients' phonological processing, we used a variety of normed tests from the Psycholinguistic Assessment for Language Perception of Aphasics (PALPA) (Kay, Lesser, & Coltheart, 1992). As the scores on Table 1 show, the patients were relatively unimpaired on all the phonological tests (Tests 9–12). They also showed minimal impairment on a sentence–picture-matching task designed to probe syntactic processing (Test 8). In this test, the subjects hear a spoken sentence that they are asked to compare against a set of three black-and-white line drawings. The sentences are all semantically "reversible" in that each actor can potentially function as the agent of the action (e.g., "the woman visits the doctor") and the main verb in each sentence had a preference to take a noun phrase argument, as determined by pretests. Half the sentences are simple active constructions and half use a passive construction. One picture correctly depicted the activity described by the sentence, one of the foils consisted of a lexical distracter, whereas the second foil consisted of a reverse role distracter, where the agent of the action becomes the recipient of the action (e.g., in which the doctor visits the woman). The patients made only one or two errors on this test and were within the range of normal controls.

In contrast, they were clearly impaired on tests of their semantic abilities. In a word–picture-matching test in which they had to match a word to a picture of an object from the same semantic category, the patients

Table 1. Neuropsychological and Language Test Scores

	Control Norms	*B. S.*	*E. K. (Time 1)*	*E. K. (Time 2)*	*J. T.*	*K. B.*
General Cognitive Tests						
1. ACE		0.65	1.19	1.83	1.77	NT
2. Ravens Matrices (max. 36)		32	30	26	36	15
3. MMSE (max. 30)		27	27	NT	23	11
4. Digit span forward (max. 14)		6	6	6	8	9
Language Tests						
1. Naming (Bunn, Tyler, & Moss, 1998)[a] (% correct)	95	38	33	21	11	17
2. Within-category word–picture match (% correct)	100	85	93	88	77	66
3. Category fluency[b]	*na*	7	7	4	1	10
4. Letter fluency[c]	38.5	14	7	8	5	8
5. Pyramids and Palm Trees (words; max. 52) (% correct)	>90	67	69	67	60	60
6. Pyramids and Palm Trees (pictures; max. 52) (% correct)	>90	63	67	58	67	67
7. Property verification test (Moss & Tyler, 2000) (% correct)						
Shared	97	94	92	83	70	
Distinctive	96	73	67	61	59	
8. Syntax: spoken sentence–picture match (% correct)	99	97	94	91	91	94
9. PALPA word rhyme judgment/spoken version (% correct)	*na*	98	95	88	92	92
10. PALPA word rhyme judgments/written version	*na*	72	62	55	59	
11. PALPA phonological segmentation of initial sounds (% correct)	97	100	100	100	85	
12. PALPA phonological segmentation of final sounds (% correct)	97	93	90	93	97	

na = not applicable.

[a] A subset of eight categories, four living and four nonliving, matched on relevant variables (see Bunn et al., 1998). Total = 70 pictures.

[b] Score averaged over four categories (animals, vehicles, tools, and fruits/vegetables).

[c] Score averaged over three letters (F, A, and S).

were impaired although control subjects are typically at ceiling (Test 2). Similarly, they were poor on a property verification study on which they had to make a verification judgment to statements about common objects (e.g., ‘‘does a cat have whiskers?’’ Test 7). The statements were of two types; they probed general properties of objects (e.g., ‘‘does a camel have legs?’’) and distinctive properties (e.g., ‘‘does a camel have a hump?’’). The patients showed preserved knowledge of the shared properties of objects but a significant impairment of distinctive properties, a pattern that we have observed in other patients with semantic deficits (Moss & Tyler, 2000). The patients were also tested on both versions of the Pyramids and Palm Trees test, one involving written words and the other involving pictures (Howard & Patterson, 1992). They were all significantly impaired compared with healthy controls.

Finally, we tested the patients on three tests of regular and irregular past tense processing. Two of these tests required the patients to produce regularly and irregularly inflected past tense forms when they occurred in spoken sentences, while the third experiment tested their ability to comprehend the spoken forms of regular and irregular past tense forms and their stems. This latter test required the patients to make speeded lexical decision responses to pairs of spoken words, and only three of the patients could reliably perform the task. We also report longitudinal data from one of the patients

(E. K.) whose performance we were able to monitor over the course of 14 months on all three tests.

RESULTS

Past Tense Elicitation Tasks

The control subjects made virtually no errors on the elicitation task developed at the Centre for Speech and Language (CSL) (Table 2). Three out of four patients also showed no significant differences in their ability to produce either regular or irregular past tense forms. B. S. and K. B. correctly inflected 95% of the regulars and 100% of the irregulars. Although E. K. correctly inflected slightly more of the regulars (86%) than the irregulars (82%) when first tested in January 2002, this difference was not significant ($\chi^2 = 0.01$, $p > .05$). When we tested her a year later, there was no difference at all between the irregulars and regulars with E. K. correctly inflecting 86% of each. Only J. T. showed a significant advantage for the regulars, correctly inflecting 100% of them compared with only 55% of the irregulars ($\chi^2 = 10.48$, $p < .05$). Given that most of the patients made so few errors on inflecting the irregulars, it was not possible to carry out an analysis of the error types. Of the 16 errors on the irregulars, 14 of these involved pure regularization (e.g., *creep* → *creeped*) and 2 involved partial regularization (e.g., *deal* → *dealded*). Both single- and dual-mechanism approaches would predict this outcome.

In further analyses, we compared high- and low-frequency words in the two conditions to test a key claim of the single mechanism account, that patients with semantic deficits will have particular difficulty with the low-frequency irregulars (Patterson et al, 2001). This is claimed to arise because low-frequency irregulars depend more upon semantics to achieve the mapping between present and past tense than high-frequency irregulars. For the frequency analysis, we divided each set of words into two bands—low and high frequencies (see Table 3). As Table 2 shows, the patients were not differentially impaired on the low- relative to high-frequency irregulars. Both K. B. and B. S. only made one error in the entire test and this was on a high-frequency regular word. In January 2002, E. K. did show a frequency effect, having more difficulty correctly inflecting low- compared with high-frequency words. However, this did not interact with regularity; she correctly inflected 73% of the low-frequency regulars and 67% of the low-frequency irregulars. This difference was not significant ($\chi^2 = 0.18$, $p > .05$). A year later, she no longer showed a frequency effect. J. T. was the only patient who clearly had more difficulty correctly inflecting low-frequency irregular words. Sixty-eight percent of the high-frequency irregulars were correctly inflected but only 32% of the low-frequency irregulars.

The pattern of results on the CSL elicitation test was broadly consistent with those for the Ullman elicitation task (see Table 2). When first tested, E. K. correctly inflected 90% of the irregular past tense forms, 75% of the regulars, and 70% of the nonwords. The difference between the regulars and irregulars was not significant ($\chi^2 = 0.6926$, $p > .05$). When tested a year later, the pattern was slightly, but not significantly different. She correctly inflected 90% of the regulars, 80% of the irregulars, and 100% of the nonwords, but none of these differences were significant (all $\chi^2 > 0.05$). Similarly, B. S. showed no significant difference in accuracy between the regulars and irregulars, correctly inflecting 100% of the regulars, 95% of the irregulars, and 100% of the nonwords. In contrast, J. T. was more accurate on the regulars (95%) and the nonwords (100%) than the irregulars (75%). The difference between the regulars and irregulars, although substantial, did not reach significance ($\chi^2 = 3.14$, $p > .05$).

Table 2. Past Tense Elicitation (% Correct)

	B. S.	*E. K. (Time 1)*	*E. K. (Time 2)*	*J. T.*	*K. B.*
CSL Past Tense Elicitation Task					
Regulars	95	86	86	100	95
Irregulars	100	82	86	55	100
CSL Past Tense Elicitation Task					
Regulars					
HF ($n = 11$)	93	100	91	100	93
LF ($n = 11$)	100	73	82	100	100
Irregulars					
HF ($n = 13$)	100	85	85	68	100
LF ($n = 9$)	100	67	89	32	100
Ullman Past Tense Elicitation Task					
Regulars	100	75	90	95	*nt*
Irregulars	95	90	80	75	
Nonwords	100	70	100	100	

CSL = Centre for Speech Language.

Intramodal Priming Task

Controls

Twelve healthy controls were tested in this study, six on each version. Analyses of their reaction times (RTs) showed a significant main effect of priming, $F_1(1,10) = 83.5$, $p < .001$; $F_2(1,124) = 128.1$, $p < .001$, and a main effect of condition, $F_1(3,30) = 39.6$, $p < .001$; $F_2(3,124) = 8.25$, $p < .001$, due to differences in overall RTs in the

Table 3. Properties of Stimuli for CSL Past Tense Elicitation Task

	Median Word Form Frequency	*Median Lemma Frequency*	*Median Imageability*
Low-frequency regulars (n = 11), e.g., *bless/blessed*	10	28	493
Low-frequency irregulars (n = 9), e.g., *bleed/bled*	10	20	486
High-frequency regulars (n = 11), e.g., *share/shared*	64	179	424
High-frequency irregulars (n = 13), e.g., *grow/grew*	75	183	435

four conditions, with RTs in the semantic condition being fastest (944 msec) and RTs in the phonological condition being slowest (1091 msec). More importantly, there was a significant Priming × Condition interaction, $F_1(3,30) = 13.0, p < .001$; $F_2(3,124) = 22.4, p < .001$. To probe the source of this interaction, we analyzed each condition separately. This analysis showed a significant priming effect of 101 msec for the regulars, $F_1(1,10) = 38.4, p < .001$; $F_2(1,40) = 40.0, p < .001$, 171 msec for the irregulars, $F_1(1,10) = 66.4, p < .001$; $F_2(1,40) = 117.3, p < .001$, and 109 msec for the semantically related pairs, $F_1(1,10) = 13.8, p < .01$; $F_2(1,22) = 37.7, p < .001$, and no priming for the phonologically related pairs (−47 msec), $F_1(1,10) = 2.29, p = .162$; $F_2(1,22) = 2.58, p = .123$. Moreover, the controls showed significantly more priming for the irregulars compared with the semantic condition, $F_2(1,62) = 5.596, p = .021$. The mean RTs and standard errors are displayed in Figure 2. This pattern of results for the healthy controls is identical to that produced by a different group of controls in a similar earlier experiments (Tyler et al, 2002).

Patients

We were only able to test E. K., B. S., and J. T. in this study, as K. B. was not available for testing. All three patients produced mean RTs that were within the normal range (E. K. at first testing = 1006 msec, E. K. at second testing = 1041 msec; B. S. = 1152 msec; J. T. = 1099 msec) (Figure 3). We carried out an ANOVA on the combined data from B. S., J. T., and E. K. and found a main effect of priming, $F_2(1,123) = 93.97, p < .001$, due to faster RTs in the related (mean RT = 1023 msec) compared with the unrelated condition (mean RT = 1194 msec) and a significant Priming × Condition interaction, $F_2(3,123) = 6.423, p = .001$, due to faster RTs in the semantic and irregular conditions (1063 and 1052 msec, respectively) compared with the regular (1135 msec) and the phonological condition (1185 msec). This was very similar to the pattern shown by the control subjects.

We then analyzed each condition separately and found that the priming effect of 283 msec for the irregulars was significant, $F_2(1,40) = 84.176, p < .001$, as was the 104-msec priming effect for the semantic condition, $F_2(1,22) = 12.673, p = .002$. The regulars also primed significantly (mean priming = 185 msec), $F_2(1,40) = 20.027, p < .001$, whereas the phonologically related items did not (mean priming = 115 msec), $F_2(1,22) = 3.120, p = .092$. In the direct comparison between the semantic and irregular conditions, the patients showed a significant interaction, $F_2(1.62) = 15.5, p < .001$, because just like the normal subjects, they showed more priming for the irregulars. However, the patients showed a greater difference in the amount of priming for the irregulars compared with the semantic condition (179 msec as opposed to 62 msec for the controls). In an analysis comparing the priming effects for patients and controls in the semantic and irregular conditions, we found a significant interaction,

Figure 2. Auditory–auditory priming study: Mean RTs and standard errors for 12 control volunteers.

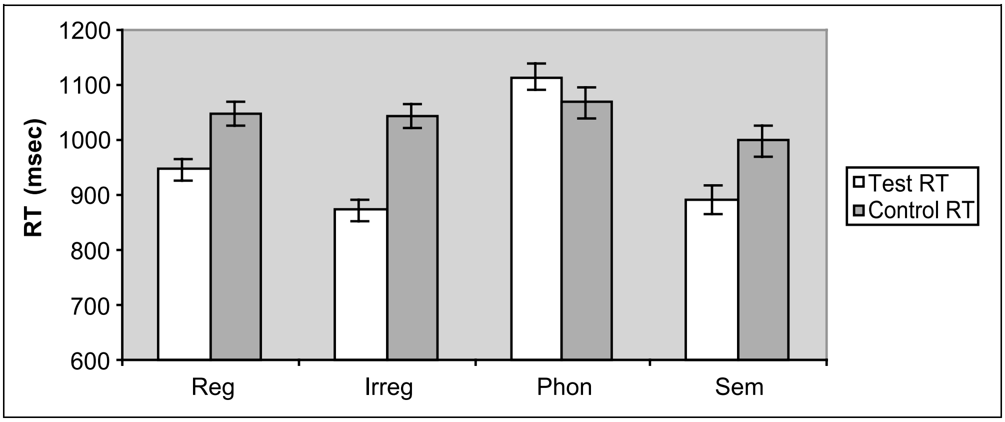
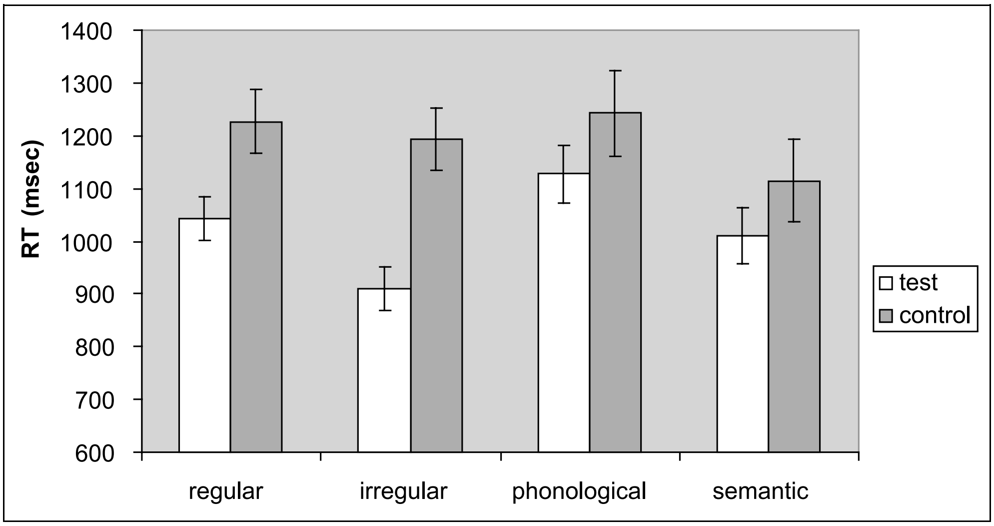


Figure 3. Auditory–auditory priming study: Mean RTs and standard errors for the patients (group data for J. T., E. K., and B. S.).



$F(1,64) = 4.64$, $p = .035$. This interaction is shown in Figure 4.

The group pattern was essentially repeated when each patient's data were analyzed separately, with one qualification—the semantic priming effect did not reach significance for any of the patients. In the first testing period, E. K. showed a main effect of priming, $F(1,110) = 65.74$, $p < .001$, and a significant Priming × Condition interaction, $F(3,110) = 4.08$, $p = .009$. Although the irregulars primed robustly (333 msec), $F(1,37) = 44.60$, $p < .001$, the priming effect of 100 msec for the semantically related pairs was not significant, $F(1,54) = 2.49$, $p = .120$. A year later, when tested a second time, she showed a significant overall priming effect, $F(1,115) = 91.93$, $p < .001$, and a significant Priming × Condition interaction, $F(3,115) = 6.25$, $p = .001$. The irregulars still primed strongly (346 msec), $F(1,38) = 82.29$, $p < .001$, but the semantically related pairs did not prime significantly (104 msec), $F(1,21) = 2.34$, $p = .141$. Similarly, B. S. showed a main effect of priming, $F(1,115) = 56.042$, $p < .001$, and a Priming × Condition interaction, $F(3,115) = 2.885$, $p = .039$. The irregulars primed strongly (243 msec), $F(1,40) = 38.941$, $p < .001$, in the absence of significant semantic priming (105 msec), $F(1,21) = 2.717$, $p = .12$. J. T. also showed a main effect of priming, $F(1,97) = 7.138$, $p < .01$, and a Priming × Condition interaction, $F(1,97) = 4.82$, $p < .01$. The irregulars produced robust priming (177 msec), $F(1,36) = 11.35$, $p < .01$, while the semantic conditions produced a marginally significant priming effect (80 msec), F 1,17) = 4.42, $p = .051$.

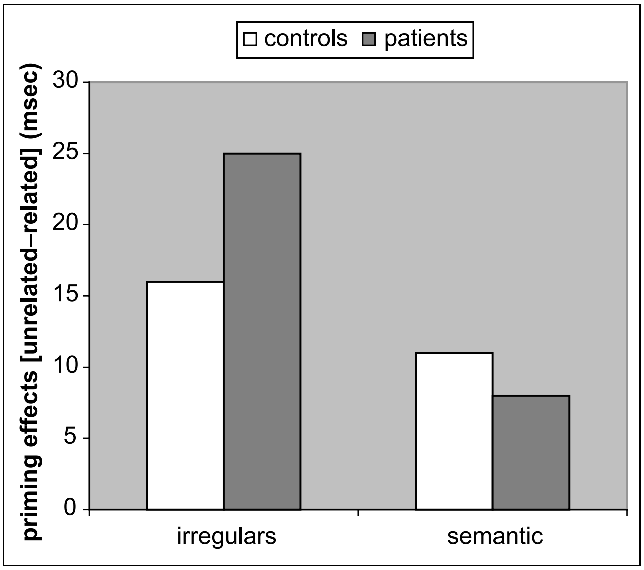


Figure 4. Auditory–auditory priming study: Priming effects across groups for the irregular and semantic conditions.

The failure of semantic priming effects to reach significance for the patients individually, as well as the statistically larger difference between semantic and irregular priming for the patients compared with the controls, indicates a significant impairment in semantic priming for this population. In contrast, their priming for the irregulars seemed to be robustly unimpaired and significant for each patient individually.

DISCUSSION

The aim of this research was to determine whether patients with semantic deficits always have associated problems in processing irregularly inflected forms, as predicted by current single mechanism accounts of neuropsychological double dissociations between English regular and irregular past tenses. To address this issue, we tested semantic dementia patients on tasks that probe the production and comprehension of regular and irregularly inflected past tense forms. We tested the patients' abilities to produce correctly inflected past tense forms from their present tense variants in two elicitation experiments. In both studies, three of the patients were able to correctly inflect both the regular and irregular past tense. Only one patient, J. T., had significantly more difficulty in inflecting the irregulars compared with the regulars. This set of results suggests that semantic deficits do not necessarily go together with difficulties in producing irregularly inflected past tense forms.

A possible argument against this interpretation of data is that the three patients who did not have difficulties producing irregularly inflected words may have milder semantic deficits than the single patient, J. T., who did have problems with the irregulars. However, the data from the semantic tests do not suggest that J. T. was more severely semantically impaired than the other three patients. On the Pyramids and Palm Trees test using either written words or pictures, the patients all scored poorly, making between 31% and 42% errors. J. T.'s error rate was 33%. Similarly, on a word–picture matching task, his error rate (23%) was within the range of the errors produced by the other patients (7–34%).

Turning to an assessment of the patients' ability to comprehend past tense forms, we found that the irregulars primed robustly whether we analyzed the patients as a group or individually, suggesting that their ability to access the irregulars from a phonological input was not impaired, even for the patient (J. T.) who had difficulties accessing irregulars in a production task. Indeed, the overall group pattern of priming results looks remarkably normal. Like the controls, the patient group showed priming for both types of past tense and for semantically related words, while phonologically related words did not prime significantly. Moreover, like the controls, the patients showed significantly greater priming for the irregulars compared with the regulars.

We have previously interpreted priming between a verb form such as *bring* and its irregularly inflected past tense form (i.e., *brought*) as evidence that the relationship between them is morphological rather than semantic (Marslen-Wilson & Tyler, 1998, 2003). Both forms of the verb map onto the same underlying stem morpheme, just as for the regulars, and it is the repeated activation of this morpheme that gives rise to priming effects (both at short and long priming delays). On this account, the basis for priming between irregularly inflected words is different from the processes that underpin priming between two semantically related but morphologically unrelated words (e.g., *coat/dress*). In the latter case, semantically related words prime because of semantic overlap between two separate lexical or morphemic representations. This predicts that semantic deficits and deficits for the irregular past tense will not necessarily pattern together—which is the pattern of results that we obtain here for the semantic dementia patients.

To account for neuropsychological dissociations in which patients are disproportionately impaired on the regular past tense, we have focused on differences in phonological processes involved in parsing an inflected form into its stem and affix. We assume that regularly inflected past tense forms are generated as combinations of stems and inflectional affixes (*open* + *ed*) and recognized by a process of phonological parsing where the speech input is segmented into a stem and its affix. Problems with the regulars arise when this phonological parsing mechanism is impaired, usually following damage to the left inferior frontal gyrus (LIFG) and associated regions (Tyler, de Mornay Davies, et al., 2002; Tyler, Randall, et al., 2002). Irregularly inflected forms are stored, just like monomorphemic words such as *table* or *grass*, as full-form representations with no internal phonological structure as combinations of stems and affixes. These words do not need to be phonologically parsed into stems and affixes as part of the on-line access process. These differences in requirements for phonological parsing, accompanied by damage to neural systems implicated in these types of analysis, gives rise to selective deficits for the regular past tense.

Turning to deficits for the irregulars, we assume (as noted above) that an irregular past tense form has a stored lexical form representation, linking to the same underlying morpheme as other forms of the same word. This predicts that deficits for the irregulars can arise if brain damage either affects stored lexical representations directly, or disrupts the mechanisms involved in the process of mapping from phonology to semantics (Marslen-Wilson & Tyler, 1998). A version of this proposal is put forward by Miozzo (2003) in the context of the anomic patient A. W., who had problems with the irregulars in the presence of intact semantics—the opposite pattern to the one reported here for three out of our four semantically impaired patients. Miozzo suggests that this patient, typical of anomic patients in general, has impairments in lexical processing as evidenced by her difficulty in retrieving a word's phonology. On the hypothesis that irregular past tense forms must be accessed as whole forms, so that alternative access routes involving decompositional mechanisms cannot be invoked, problems in accessing stored lexical representations should differentially disadvantage the irregulars compared with the regulars.

There are some hints in the priming data that J. T., the one patient who showed difficulty in producing irregularly inflected words, may also have phonological problems: He made many lexical decision errors (31% errors) on the items in the phonological condition and more than in any other condition (11% in the regular, 5% in the irregular, 12% in the semantic conditions). The other patients did not show this pattern: B. S. made 8%, 4%, 0, and 2% errors in the phonological, regular, irregular, and semantic conditions, respectively; E. K. at Time 1 made 8%, 8%, 3%, and 2% errors on the phonological, regular, irregular, and semantic conditions, respectively, and 4%, 6%, 1%, and 2%, respectively, errors in those conditions at the second time of testing. Similarly, J. T. had a high error rate (30%) on the phonologically related foils in the experiment, such as *gossip/goss*. These data, however, are only suggestive. Further research is needed to determine the nature of this potential phonological deficit, and whether there is a more general relationship between phonological processing deficits and problems in accessing stored lexical forms.

One issue that is raised by these results is why the patients, as a group, show any semantic priming at all when they each have pronounced semantic deficits. This is not the first time that semantic dementia patients have been observed to show semantic priming while their performance on standard off-line tests shows them to be profoundly impaired. We have previously reported semantic priming in three semantic dementia patients (A. M.: Tyler & Moss, 1998; F. M.: Tyler, Moss, Patterson, & Hodges, 1997; P. P.: Moss, Tyler, Hodges, & Patterson, 1995). Given that these patients had been unambiguously diagnosed as having a semantic deficit, we had not initially predicted that they would show priming for semantically related words. The fact that priming can still be obtained, albeit at a significantly reduced level, suggests that it is not an all-or-none phenomenon. Significant priming effects may not require the activation of all of the information associated with a concept. All that may be required is that the semantic relationship between the two related words (e.g., *onion/carrot*) should be stronger, to some criterial degree, than between the two unrelated words (e.g., *desk/carrot*). This would allow semantic priming effects even in a damaged system so long as some semantic information is preserved, especially if it is the shared properties of concepts that are preserved, since it is these that provide the basis for semantic overlap between related concepts.

It has been independently demonstrated that the shared properties of concepts are indeed preserved following brain damage. These properties are more highly correlated with each other, and correlated properties are relatively preserved following damage (Moss & Tyler, 2000; Tyler et al, 2000; Tyler & Moss, 2001; Devlin, Gonnerman, Andersen, & Seidenberg, 1998; McRae, de Sa, & Seidenberg, 1997). Moreover, studies with patients who have semantic deficits have shown that the shared properties of concepts tend to be preserved while the distinctive properties tend to be impaired (Tyler & Moss, 2001; Moss, Tyler, Durrant-Peatfield, & Bunn, 1998). The patients in the current study show the same pattern. In a verification task, they were impaired at verifying the distinctive properties of concepts while relatively preserved on their shared properties (Table 1). If, as argued above, it is the coactivation of these shared properties that primarily drives priming in the intact system, then this would explain the preservation of some degree of semantic priming in the semantic dementia population.

In summary, E. K. and B. S. did not show any differential impairment for the irregulars compared with the regulars on either elicitation or priming tasks and K. B. did not show a disproportionate deficit for the irregulars compared with the regulars in the elicitation task. Only J. T. showed an association of semantic deficit and problems with the irregulars. Moreover, when the patients did make errors on the irregulars, they did not exhibit the pattern of effects predicted by the single mechanism account (Patterson et al, 2001), with a higher proportion of errors on low-frequency items. These results show that there is no necessary association between a semantic deficit and problems with the irregular past tense. Although the two often do co-occur, as we and others have previously documented, they can evidently also occur independently of each other. This dissociation indicates that a separate set of functional capacities is implicated here, supporting the access of stored lexical representations. An important issue for future research is to identify the neural infrastructure for these access processes, so that we can better determine the conditions under which semantic deficits will co-occur with deficits for the irregulars.

The present results, together with the results for normal subjects addressed earlier (Marslen-Wilson & Tyler, 1998), argue against the claim that the relationship between irregular past tense forms and their stems is primarily a semantic rather than a morphological relationship. This, in turn, undermines the evidence for the type of single system account of lexical representation in which morphological structure can be captured solely on the basis of phonological and semantic relationships (Patterson et al, 2001; Joanisse & Seidenberg, 1999).

METHODS

Subjects

In addition to the four semantic dementia patients, a group of seven control subjects (aged between 56 and 69 years) were tested on the elicitation task and a group of 12 subjects (aged 60–73 years) were tested on the priming study.

Past Tense Production: Elicitation Studies

We tested the patients on two elicitation experiments designed to probe their ability to generate past tense forms from their stems. In the first elicitation test, described in Ullman et al. (1997), subjects were presented with sentences containing the present tense forms of regular and irregular words, together with a set of nonwords, for past-tense generation. We used this test to directly compare our patients with others reported in the literature who have deficits in generating past tense forms.

For the second elicitation task, we selected a set of 22 regular and 22 irregular verbs, matched as closely as possible on form and lemma frequency (Baayen, Piepenbrock, & Gulikers, 1995) and imageability (Coltheart, 1981). The median word form frequency was 35 for the regulars and 36 for the irregulars. The median lemma frequency was 92 for the regulars and 110 for the irregulars. The median imageability was 485 for the regulars and 470 for the irregulars. A two-sentence context was created for each verb, where the second sentence was incomplete and required a verb inflected for the past tense. For example, for the sentence "My nose sometimes bleeds. Last night it . . .," the correct response would be *bled*. The test stimuli were preceded by five practice trials. The sentences were read aloud to the subjects who were encouraged to produce a past tense form appropriate for the sentence.

Past Tense Comprehension: Auditory Priming Study

To test patients' abilities to comprehend spoken past tense forms, we designed an intramodal auditory–auditory priming study, contrasting the regulars and irregulars. We chose to use a priming study to avoid some of the pitfalls associated with testing patients on tasks that make heavy metalinguistic demands. In this experiment, target words, which were verb stems (such as *pull*, *sing*), were preceded by a regularly or irregularly inflected past tense prime (*pulled*, *sung*) or by an unrelated control word. In addition to the two main experimental conditions, we included two other conditions. The first was a semantic priming condition in which the prime-target pairs were semantically but not phonologically or morphologically related (*pig*/*horse*). We included this to determine whether the patients would show evidence of a semantic deficit in the same type of on-line task as used to assess their performance on the past tense forms. The fourth condition consisted of a phonological priming condition, in which the prime-target pairs were phonologically but not semantically or morphologically related (*paint*/*pain*), which acted as a control for the effects of phonological similarity. Since the inflected-stem pairs share a great deal of phonological overlap, we need to be able to separate out phonological from morphological priming effects.

Materials

We selected 42 prime-target pairs in each of the past tense conditions (regular/irregular) and 24 pairs for the 2 control conditions (semantic/phonological). In both the regular and irregular past tense conditions, the primes were all inflected past tense forms (e.g., *fixed*, *glanced*; *stuck*, *brought*) and the targets consisted of their stems, all of which were one or two syllables (*fix*, *glance*, *stick*, *bring*). Items in the phonological control condition consisted of morphologically simple monosyllabic pairs (e.g., *lamp*/*lamb*, *plump*/*plum*) that were not semantically related. The proportion of consonant-vowel-consonant (CVC) and consonant-vowel (CV) overlap between prime and target was matched to the regular past tense pairs. In all of the conditions, we avoided homophones. The two past tense sets and the phonological set were matched as closely as possible for test prime, control prime, and target frequency and number of syllables (see Table 4). The fourth condition consisted of pairs of semantically related words that were either phonologically or morphologically related (e.g., *shore*/*coast*; *alley*/*lane*). For this condition, we selected pairs of semantically related words that were highly semantically related (but not associatively) and of relatively high frequency. This was to ensure significant semantic priming effects in control subjects to provide a basis for evaluating semantic priming in the patients. A semantic relatedness pretest was carried out in which 15 subjects were asked to rate pairs of words according to their degree of semantic relatedness on a scale of 1–9, where 1 was *highly unrelated* and 9 was *highly related*. The mean semantic relatedness rating for the prime-target pairs was 7 (SD = 1.02).

Each prime word was matched to a control word in frequency and number of syllables (see Table 4). In addition to the 132 test pairs, we included 80 real word filler pairs, making a total of 212 real word pairs. The fillers were an equal mixture of unrelated simple primes/past tense targets, simple primes/(-s) inflected targets,x (-s) inflected primes/simple targets, simple primes/simple targets, and unambiguous noun pairs. We also included 148 legal word/nonword pairs, which were a mixture of phonologically unrelated prime-target pairs, phonologically related pairs with targets derived from regularly inflected past or present tense forms, phonologically related pairs with targets made from irregularly inflected forms, and pairs with irregular verbs as primes.

Design and Procedure

Test and filler items were pseudorandomly dispersed throughout the test list. We constructed two lists of stimuli so that the target word only occurred once per

Table 4. Intramodal Priming Study: Median Frequencies of Stimuli

	Test Prime	*Target*	*Control Prime*
Regulars	5.5	6	4
Irregulars	6	7	5
Phonological	14	18	13
Semantic	16	10	15

version. All of the stimuli were recorded by a female native speaker of British English, digitized at 22 kHz, and markers placed at the acoustic onset of each target word. The markers triggered a timing device that measured the subject's reaction time to the target word. Primes and targets were recorded onto a DAT tape for presentation to subjects. Subjects heard prime–target pairs and were asked to make a lexical decision to the target by pressing a response key.

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Note

1. These data were kindly provided by Elizabeth Jeffries.

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