Getting to the Meaning of the Regular Past Tense: Evidence from Neuropsychology

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Abstract

■ Neuropsychological impairments of English past tense processing inform a key debate in cognitive neuroscience concerning the nature of mental mechanisms. Dual-route accounts claim that regular past tense comprehension deficits reflect a specific impairment of morphological decomposition (e.g., *jump* + *ed*), disrupting the automatic comprehension of word meaning accessed via the verb stem (e.g., *jump*). Single-mechanism accounts claim that the deficits reflect a general phonological impairment that affects perception of regular past tense offsets but which might preserve normal activation of verb semantics. We tested four patients with regular past tense deficits and matched controls, using a paired auditory semantic priming/lexical decision task with three conditions: uninflected verbs (*hope*/*wish*), regular past tense primes (*blamed*/*accuse*), and irregular past tense primes (*shook*/*tremble*). Both groups showed significant priming for verbs with simple morphophonology (uninflected verbs and irregular past tenses) but the patients showed no priming for verbs with complex morphophonology (regular past tenses) in contrast to controls. The findings suggest that the patients are delayed in activating the meaning of verbs if a regular past tense affix is appended, consistent with a dual-route account of their deficit. ■

INTRODUCTION

A key debate in cognitive neuroscience concerns the nature of the mental mechanisms involved in language processing. This is an important and controversial topic that relates to the basis of uniquely human abilities. Dual-route accounts (e.g., Marslen-Wilson & Tyler, 2003; Pinker & Ullman, 2002; Ullman, 2001; Baayen & Schreuder, 1999; Clahsen, 1999; Ullman, Corkin, et al., 1997; Caramazza, Laudanna, & Romani, 1988) propose a fundamental distinction between the associative memory processes required to store and retrieve arbitrary information (e.g., how to pronounce the word *yacht* and what this word refers to) and procedures that combine units of stored knowledge (e.g., to create new words, such as *texted*). In contrast, single-mechanism accounts (e.g., Bird, Lambon-Ralph, Seidenberg, McClelland, & Patterson, 2003; McClelland & Patterson, 2002; Patterson, Lambon-Ralph, Hodges, & McClelland, 2001; Joanisse & Seidenberg, 1999; Rumelhart & McClelland, 1986) propose a uniform associative mechanism that learns the range of statistical regularities between word form and meaning.

For almost two decades, the debate between these theoretical camps has taken the English past tense as a critical battleground (beginning with Rumelhart & McClelland, 1986, and Pinker & Prince, 1988). This is because the regular past tense in English appears to be a paradigmatic example of a combinatorial procedure, operating in language production to concatenate morphemes (the smallest meaningful elements of language) into words, and in language comprehension to decompose words into morphemes. The regular past tense is formed by adding the inflection *–ed* to verb stems, which is realized phonetically as the three allomorphs /d/, /t/, or /id/, depending on the voicing of the stem final phoneme. It applies to the vast majority of English verbs including neologisms (e.g., *texted*) and applies as the default to nonsense words (e.g., *plim*/*plimmed*) (Prasada & Pinker, 1993). In contrast, there is a small minority of verbs that do not fit this pattern. These irregular forms are not predictable from their verb stems (e.g., *bring*/*brought* but *ring*/*rang* and *fling*/*flung*) and are rarely extended to new verbs. The regular and irregular past tense, despite being syntactically and semantically equivalent, differ in both productivity and *morphophonology*, that is, the phonological realization of their morphological status (e.g., verb + past).

Acquired language disorders have provided evidence for the morpheme as a unit of lexical processing. The substitution of inflected forms with morphologically simple words is characteristic of nonfluent aphasia, as are morphological errors in deep dyslexia (Coltheart, 1980). Aphasiology has also provided evidence that impairments of different categories of morphology can be dissociated (Miceli & Caramazza, 1988; Goodglass &

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Journal of Cognitive Neuroscience 17:7, pp. 1087–1097

Berko, 1960). The current research focuses on patients who have difficulties processing spoken regular past tenses, following acquired damage to the left peri-sylvian cortex (e.g., posterior left inferior frontal gyrus, left superior temporal gyrus, and sometimes underlying subcortical structures, such as the basal ganglia) (Tyler, de Mornay-Davies, et al., 2002). Their deficit was first demonstrated using paired auditory priming, a paradigm that requires volunteers to make speeded lexical decision responses (i.e., word/nonword judgments) to targets preceded by related or unrelated prime words (Marslen-Wilson & Tyler, 1997). Healthy volunteers show response facilitation following morphologically (e.g., *jumped/jump* or *taught/teach*) and semantically (e.g., *blame/accuse*) related primes. The patients, in contrast, showed intact irregular past tense morphological priming (e.g., *taught/teach*) and semantic priming (e.g., *blame/accuse*), but no morphological priming from the regular past tense (e.g., *jumped/jump*) (Tyler, de Mornay-Davies, et al., 2002; Marslen-Wilson & Tyler, 1997, 1998). These patients form a double dissociation with patients with middle and inferior temporal lobe damage, who show intact regular past tense morphological priming but no irregular past tense or semantic priming (Tyler, de Mornay-Davies, et al., 2002; Marslen-Wilson & Tyler, 1997, 1998).

Dual-route accounts of the English past tense (Ullman, Izvorski, et al., in press; Marslen-Wilson & Tyler, 2003; Pinker & Ullman, 2002; Ullman, 2001; Ullman, Corkin, et al., 1997) propose that the double dissociation between regular and irregular past tense forms reflects damage to separable but interdependent processing mechanisms, operating in parallel. Irregular past tense forms and monomorphemic words are assumed to be accessed as full forms, a process postulated to rely on the left inferior temporal gyrus (Tyler, de Mornay-Davies, et al., 2002), the tempero-parietal cortex, and medial-temporal lobe structures (Pinker & Ullman, 2002). Regularly inflected words, in contrast, are assumed not to require full-form recognition. They can be decomposed into stems and affixes by a process of phonological parsing, argued to rely on regions of the left peri-sylvian cortex including Broca's area (Pinker & Ullman, 2002; Tyler, de Mornay-Davies, et al., 2002; Ullman, 2001). It is this process that is thought to be impaired in the patients. The ''Words and Rules'' theory of Pinker and colleagues and related views, such as Ullman's Declarative/Procedural model (e.g., Ullman, Izvorski, et al., in press; Pinker & Ullman, 2002; Ullman, 2001; Ullman, Corkin, et al., 1997) propose that regular past tense forms can be recognized as sequences of morphemes, but factors such as high-frequency or phonological similarity of the stem to an irregular verb lead some regular past tense forms to be stored and recognized in full. Similar claims for the storage of high-frequency regularly inflected forms have also been made based on evidence from errors in naturally occurring speech and speeded past tense generation (Stemberger & MacWhinney, 1986).

In our related dual-route account of spoken word recognition (e.g., Marslen-Wilson & Tyler, 2003), however, we assume that words with overt inflectional affixes are not stored in full and always require morphological decomposition. The claim that morphologically complex words are decomposed into stems and affixes in word recognition is not new (e.g., Taft & Forster, 1975). However, the majority of models making this claim concern visual word recognition and propose that decomposition occurs either before (Taft & Forster, 1975) or in parallel (Baayen & Schreuder, 1999; Caramazza et al., 1988) with full-form recognition. In the auditory domain where the stimulus unfolds over time, however, it seems plausible to assume that decomposition might be sufficient for lexical access, as stems are encountered prior to suffixes.

In contrast, single-mechanism accounts propose that the double dissociation between the regular and irregular past tense reflects general impairments of phonology or semantics in an undifferentiated processing system (Bird et al., 2003; McClelland & Patterson, 2002; Patterson et al., 2001; Joanisse & Seidenberg, 1999). These accounts claim that irregular past tense processing is differentially affected by semantic impairment because it relies on word meaning to compensate for the relatively low-type frequency of irregular forms. They argue that regular past tense processing is differentially affected by phonological impairment because the regular past tense adds extra phonemes to the verb stem (e.g., /t/ /d/ offsets), which are argued to lack perceptual salience (Joanisse & Seidenberg, 1999) and to increase phonological complexity (Bird et al., 2003).

In support of the single-mechanism account, Bird et al. (2003) reported that an apparent regular past tense deficit in speech production disappeared once phonological structure was controlled. In an untimed same–different judgment task on spoken words, they found that a group of aphasic patients were equally impaired on both morphological (e.g., *man/manned*) and non-morphological (e.g., *men/mend*) discriminations. However, although some instances of regular past tense deficits may relate to phonological difficulty, this is not true for all patients. Tyler, Randall, and Marslen-Wilson (2002) reported that a group of aphasic patients were significantly slower to detect the difference between spoken regular past tenses and their stems (e.g., *called/call*) relative not only to irregular pairs (e.g., *wrote/write*) but also to phonologically matched words (e.g., *bald/ball, boat/bite*) and nonwords (e.g., *dalled/dall, poat/pite*) and to word pairs differing by a single phoneme (e.g., *clay/claim*) or feature (e.g., *cod/cot*). This pattern of performance suggests that their regular past tense comprehension deficit is specific to processing complex morphophonology, rather than general phonological features of the regular past tense. Moreover, some of the patients with regular past tense deficits performed normally on standard neuropsychological tests of phonological processing. Thus, the association between regular past tense deficits and general phonological impairments is inconsistent, weakening the case for a causal link between them.

Dual-route and single-mechanism accounts have focused on access to lexical form as the source of regular past tense deficits, but have had little to say about semantic processing. This is because the majority of patients reported with these deficits are Broca's aphasics, and Broca's aphasia is typically associated with preserved knowledge of word meaning. For example, Broca's aphasics perform normally in neuropsychological tests of semantic knowledge, such as picture naming, word–picture matching, and property verification (Tyler, de Mornay-Davies, et al., 2002). Although it has been disputed that Broca's aphasics have intact automatic processing of word meaning (Blumstein, 1997), many carefully controlled studies have found that they show spared semantic priming from morphologically simple words (e.g., Hagoort, 1997; Tyler, Ostrin, Cooke, & Moss, 1995). Indeed, all the patients reported as showing regular past tense deficits in morphological priming show intact semantic priming for monomorphemic words (Tyler, de Mornay-Davies, et al., 2002; Marslen-Wilson & Tyler, 1997, 1998). Their semantic abilities are consistent with the location of their brain damage, which tends to be confined to the left inferior frontal gyrus and superior temporal gyrus and does not include the inferior and middle temporal cortex or the temporal poles, unlike patients with semantic impairments (Gitelman, Ashburner, Friston, Tyler, & Price, 2001; Mummery et al., 2000).

The current study investigated whether patients' difficulty with the regular past tense disrupts their automatic comprehension of word meaning. Our dual-route account predicts that an impairment of morphophonological parsing should disrupt the automatic processes of spoken word comprehension, even if semantic representations and processes are intact. This is because we assume that parsing words with complex morphophonology is necessary in order to access the verb stem, associated with the meaning of the verb. Other dual-route accounts, including the ''Words and Rules'' theory (Pinker & Ullman, 2002) and the Declarative/Procedural model (Ullman, Izvorski, et al., in press; Ullman, 2001; Ullman, Corkin, et al., 1997), do not make this assumption, as they claim that some words with complex morphophonology can be recognized as full forms. Single-mechanism accounts postulate that patients with a general phonological disorder have difficulties perceiving the offsets of words in the regular past tense, which might leave automatic activation of verb semantics intact. For example, although a patient may encounter difficulties perceiving the /t/ offset of the word *jumped*, this would not necessarily prevent the perception and comprehension of the embedded verb stem *jump*. In addition, difficulties perceiving /t/ and /d/ offsets might mean that when patients hear regular past tenses followed immediately by their stems (as in morphological priming and phonological same/difference judgments), they are perceived as identical. Bird et al. (2003) suggest that this could explain the patients' difficulty in detecting the difference between regular past tense/stem pairs. If single-mechanism accounts are correct, then abnormal morphological priming might reflect response interference due to difficulties perceiving prime offsets or processing two very similar forms in close succession, rather than a disruption of automatic processing due to complex morphophonology, as claimed by dual-route accounts.

We used paired auditory semantic priming to assess automatic activation of word meaning in patients with a regular past tense deficit in auditory comprehension (as indicated by impaired morphological priming). This paradigm capitalizes on the patients' spared speech comprehension and does not require reading, writing, or speech production, any of which might be impaired. The underlying basis for semantic priming is disputed (Neely, 1991) and intact semantic priming does not predict intact performance on untimed measures of semantic comprehension (e.g., Milberg & Blumstein, 1981). The patients in the current study show spared semantic processing in timed and untimed measures of semantic processing, allowing us to use semantic priming to index automatic access to lexical representations and the extent to which this is affected by morphophonology rather than as a test of semantic abilities. Recent data from healthy subjects confirm that both regular and irregular stems and their past tense forms prime semantically related words robustly (Longworth, Randall, Tyler, & Marslen-Wilson, 2001). This suggests that differences in processing regular and irregular past tense forms do not normally affect the time course of semantic activation. Thus, if patients activate verb meaning normally, we would expect them to show semantic priming from both the regular and irregular past tense in addition to semantic priming from uninflected verb stems.

We tested patients with stimuli from our previous semantic priming study carried out with young volunteers (Longworth, Randall, et al., 2001) and compared their performance with that of age-matched healthy controls. Although the main interest of the current study was whether the patients would show semantic priming from regular past tense prime/target pairs (e.g., *blamed/accuse*), we included other verb conditions in order to provide appropriate contrasts. Verb stem prime/target pairs (e.g., *hope/wish*, *speak/talk*) were used to establish whether semantic activation from uninflected verbs is intact. Irregular past tense prime/target pairs (e.g., *slept/doze*) were used to determine whether any failure of priming is due to tense marking in general, whether regular or irregular. If the patients have a specific difficulty in parsing complex morphophonology that disrupts automatic spoken word comprehension, then they should show abnormal semantic priming from the regular past tense. If the patients have a general phonological impairment that affects their ability to detect word final /t/ and /d/ phonemes, as claimed by the single-mechanism account, then we would expect the patients to show intact semantic priming from regular past tense forms because these will be perceived as uninflected stems.

Patients

Four patients were tested (3 women and 1 man), aged between 41 and 66 years. All four patients had sustained damage to regions of the left peri-sylvian cortex as a result of a cerebrovascular accident (CVA) (see Figure 1). The language deficits and neuropathology of three of these patients (DE, AS, and MR) have been described in detail elsewhere (Tyler, de Mornay-Davies, et al., 2002; Tyler, Randall, et al., 2002). All four patients show regular past tense deficits in morphological priming.

Patient SD

Patient SD is a right-handed woman born in 1960, who suffered a cerebral aneurysm and hematoma in 1991. A magnetic resonance imaging (MRI) scan taken in August 1998 revealed a left hemisphere (LH) lesion affecting the ventral and anterior part of the frontal lobe, Broca's area, the superior temporal gyrus, putamen, and caudate (see Figure 1). Unlike the other patients, SD does not have the typical features associated with Broca's aphasia. She performed at ceiling on a sentence–picture matching test for comprehension of semantically reversible sentences in active and passive constructions (Tyler, de Mornay-Davies, et al., 2002), showing no evidence of agrammatism, and her speech is fluent. She was tested for the current study at age 41.

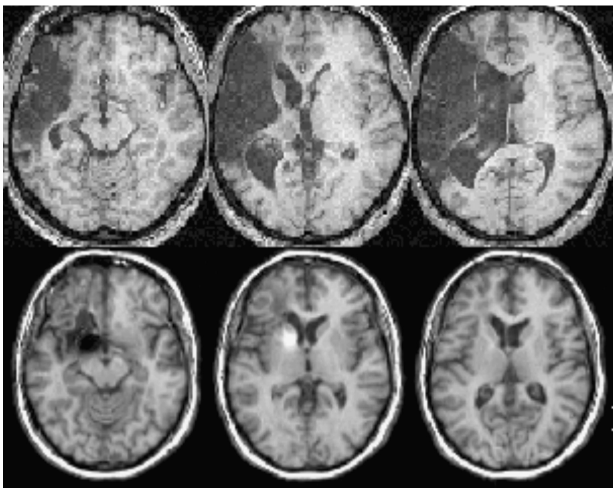

Figure 1. MRI scans of the lesions of Patients DE (top row) and SD (bottom row) showing axial slices in neurological convention (left = left) at −12, 0, and +8 mm from the plane of the anterior and posterior commissures.

Patient DE

Patient DE is a right-handed man born in 1954 who suffered a left middle cerebral artery (MCA) infarct after a road traffic accident in 1970. He was tested for the current study at age 47. An MRI scan taken in 1996 revealed a LH lesion affecting the posterior inferior frontal lobe and extending inferiorly to the superior and middle temporal gyri (see Figure 1). His CVA resulted in nonfluent aphasia, agrammatism, and deep dyslexia, and his language abilities have been investigated in-depth in previous neuropsychological research (e.g., Tyler, 1985; Patterson & Marcel, 1977). As part of this previous research, he has shown significant semantic priming from monomorphemic words (e.g., Marslen-Wilson & Tyler, 1997).

Patient AS

Patient AS is a right-handed woman born in 1943, who suffered a left MCA hemorrhage in August 1998. A CT scan taken in September 1998 revealed a hypodensity in Broca's area and the left superior temporal gyrus. Aneurysm clips precluded the possibility of an MRI scan. Patient AS has nonfluent speech, agrammatic comprehension, and a mild hearing impairment (a threshold of 25 dB at 2000 Hz in her right ear and at 500 Hz in her left ear). She was tested for the current study at age 58.

Patient MR

Patient MR is a right-handed woman born in 1935 who suffered a left MCA infarct in 1986. She had a CT scan in 1996, which revealed a large LH lesion affecting the left prefrontal cortex including Broca's area, the insula and auditory cortex, the supramarginal gyrus, and the paraventricular and supraventricular areas of the left frontal and parietal lobes. Aneurysm clips precluded the possibility of an MRI scan. She has dysfluent speech, agrammatic comprehension, and a moderate binaural hearing impairment (e.g., a threshold of 25–40 dB) across the frequency range. She was tested for the current study at age 66.

Healthy Age-Matched Controls

A group of 10 right-handed, healthy volunteers (7 women and 3 men), aged between 44 and 69 years, were recruited from the participant panel of the MRC Cognition and Brain Sciences Unit and tested under the same conditions as the patients. Each volunteer was matched to an individual patient in terms of sex, age (±5 years), and education (all patients and controls left education after secondary school). Audiometric screening (at 500, 1000, 2000, and 4000 Hz) indicated that six control volunteers showed patterns of mild to moderate hearing loss similar to that of Patients AS and MR (e.g., thresholds between 25 and 40 dB).

RESULTS

Response Times

We assessed the effects of group (patient, control), condition (stems, regular and irregular past tense), and prime type, (related, unrelated) on lexical decision responses using repeated-measures analysis of variance. The results for both groups are summarized in Table 1, and the amount of priming (the difference in response times following related and unrelated primes) is shown in Figure 2. The patients' mean response times for experimental items ranged from 935 to 1217 msec and their response accuracy ranged from 95% to 100% correct. The mean response times for the controls ranged from 708 to 1106 msec, unsurprisingly faster than the patients, but their response accuracy was similar, ranging from 91% to 100% correct.

There were significant main effects, across participants (F_1) and items (F_2), of priming [$F_1(1,24) = 36.81$, $p < .001$; $F_2(1,92) = 111.9$, $p < .001$] and group [$F_1(1,24) = 17.83$, $p < .001$; $F_2(1,92) = 463.52$, $p < .001$], but not condition [$F_1(2,48) = 2.62$, $p = .08$; $F_2 < 1$]. The main effect of group is expected because the patients (mean RT = 1076 msec) had longer response times than the age-matched controls (mean RT = 859 msec), possibly reflecting the fact that three patients used their nondominant hand to make responses, due to right-sided hemiparesis. More importantly, the main effect of priming is qualified by a significant three-way interaction between group, condition, and prime type [$F_1(2,48) = 3.5$, $p < .05$; $F_2(2,92) = 3.15$, $p < .05$].

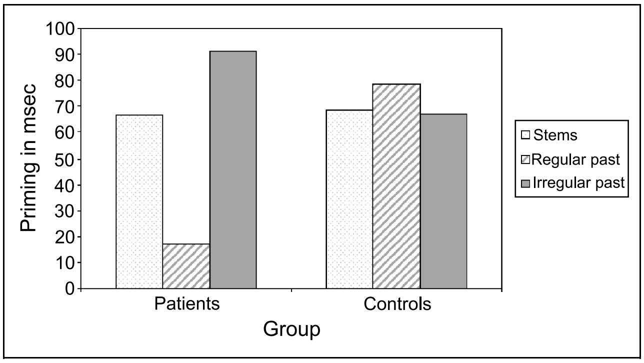

Figure 2. Semantic priming in patients and healthy, age-matched controls.

Analysis of the simple effects showed that priming for each group depended on condition. Uninflected verb stems primed related targets [$F_1(1,24) = 26.8$, $p < .001$; $F_2(1,30) = 37.26$, $p < .001$] by 69 msec, with no interaction with group [$F_1 < 1$; $F_2(1,30) = 3.02$, $p = .09$]. Irregular past tenses primed responses by 73 msec [$F_1(1,24) = 27.57$, $p < .001$; $F_2(1,31) = 53.15$, $p < .001$], again with no interaction with group (both Fs < 1). Only the regular past tense condition showed an effect of priming that interacted with group [Priming: $F_1(1,24) = 28.55$, $p < .001$; $F_2(1,31) = 24.42$, $p < .001$; Interaction: $F_1(1,24) = 7.167$, $p = .013$; $F_2(1,31) = 15.71$, $p < .001$]. This was because the control group showed a significant 79-msec priming effect for the regular past tense [$F_1(1,18) = 27.87$, $p < .001$; $F_2(1,31) = 60.38$, $p <$

Table 1. Summary of Results for Both Groups

		Patients			*Controls*		
		Related	*Unrelated*	*Diff.*	*Related*	*Unrelated*	*Diff.*
Stems	Mean RT	1053	1120	67**	823	892	69***
	SD	152	139		107	115	
	% correct	98	98	0	98	97	1
Regular past	Mean RT	1066	1082	16	837	915	78***
	SD	119	161		77	101	
	% correct	98	100	2	98	93	5*
Irregular past	Mean RT	1029	1121	92***	824	891	67***
	SD	122	175		107	128	
	% correct	100	98	2	98	94	4**

*$p < .05$.

**$p < .01$.

***$p < .001$.

.001], but the 17-msec priming effect for the patients was not significant [$F_1(1,6) = 1.82$, $p = .23$; $F_2 < 1$].

An alternative interpretation of the three-way interaction might be that the patients were faster following unrelated primes in the regular past tense relative to other conditions, whereas the age-matched controls were slower for the same items. However, although the interaction between group and condition for unrelated primes is significant across subjects, there is only a trend towards significance across items [$F_1(2,48) = 3.61$, $p = .035$; $F_2(2,92) = 2.43$, $p = .093$]. Healthy controls did not show a significant condition effect for unrelated primes [$F_1(2,36) = 2.426$, $p = .103$; $F_2 < 1$], and the patients showed a condition effect that was significant only by subjects and not by items [$F_1(2,12) = 4.96$, $p = .027$; $F_2 < 1$]. Thus, although the patients were faster to respond following some unrelated primes in the regular past tense condition than in other conditions, this is not consistent across words in the regular past tense.

Post hoc Analyses

It would be possible to interpret these results as being compatible with a single-mechanism account if it could be demonstrated that the patients' semantic priming for the regular past tense were disrupted by phonological features of the regular past tense, rather than complex morphophonology. Phonological distortions of prime words have been reported to affect semantic priming differently for anterior aphasics compared with healthy volunteers (Utman, Blumstein, & Sullivan, 2001). However, post hoc analyses indicated that the pattern of priming in the current patients does not reflect phonological features of the prime stimuli. For example, priming did not correlate with phonological features of primes such as the number of phonemes ($r = -.12$, $p = .24$) or syllables ($r = -.164$, $p = .11$), or the number of phonemes in prime onsets ($r = .036$, $p = .72$) or offsets ($r = -.13$, $p = .2$). The presence or absence of the coronal stop offsets that characterize the regular past tense (/d/ /t/) did not affect priming significantly ($t = .54$, $df = 96$, $p = .59$). Moreover, even though a subset of the regular past tense primes featured offsets uniquely predictive of the past tense and derived forms (e.g., the /md/ of *blamed*), these offsets did not have a significant effect on priming ($t = -1.01$, $df = 96$, $p = .32$).

Both the "Words and Rules" theory and related dual-route views claim that high-frequency regular forms can be stored and processed as full forms. This claim is supported by evidence from speech production errors in healthy adults, which shows that high-frequency regularly inflected forms are less susceptible to phonological and no-marking (e.g., *he *talk*) errors than low-frequency forms (Stemberger & MacWhinney 1986). If it is assumed that morphological parsing delays semantic activation, then the claim predicts that stored high-frequency regulars should produce more semantic priming than low-frequency forms that require decomposition. We would not make this prediction because we assume that all regular past tense forms require morphological parsing in speech comprehension. In the current study, age-matched controls showed a trend towards an interaction between semantic priming and word form frequency for regular past tense primes [$F(1,12) = 3.56$, $p = .084$]. This was not in the direction predicted by the "Words and Rules" theory, as the highest frequency regulars (top quartile) produced less semantic priming (70 msec) than the lowest frequency regulars (bottom quartile) (117 msec). The patients showed no significant difference ($F < 1$) in semantic priming between the highest and lowest frequency regulars. Neither group showed a significant correlation between frequency and priming for the regular past tense and there were no significant interactions between regular past tense priming and frequency using either mean or median frequency splits. A design in which the frequency of both related and unrelated primes was manipulated would provide a stronger test of different dual-route accounts. However, the assumption that morphological parsing delays semantic activation may be incorrect, as our earlier research indicated no differences in semantic priming between stems and regular past tense forms (Longworth, Randall, et al., 2001).

Response Accuracy

The d' for patients (mean $d' = 3.52$, $SD = 0.76$) and age-matched controls (mean $d' = 3.16$, $SD = 0.14$) does not differ significantly ($t = 0.92$, $df = 3.08$, $p = .42$), suggesting that they did not differ in their overall ability to categorize spoken stimuli as words or nonwords. The patients were slower to respond but their responses to the experimental stimuli were more accurate (99% correct) than those of the age-matched controls (96%) [$F_1(1,24) = 5.34$, $p < .05$; $F_2(1,92) = 12.34$, $p < .001$]. They showed no significant priming effects on response accuracy in any condition, presumably due to their high levels of accuracy overall [Stems: $F_1(1,6) = 1$, $p > .05$; $F_2 < 1$; Regular past tense: $F_1(1,6) = 2$, $p > .05$; $F_2(1,31) = 2$, $p > .05$; Irregular past tense: $F_1(1,6) = 1.95$, $p > .05$; $F_2(1,31) = 3.13$, $p > .05$]. The controls, who were faster but more error prone, showed significant priming effects on response accuracy for past tense conditions [Regular past tense: $F_1(1,18) = 12.47$, $p < .01$; $F_2(1,31) = 4.86$, $p < .05$; Irregular past tense: $F_1(1,18) = 12.96$, $p < .01$; $F_2(1,31) = 5.08$, $p < .05$], but not for uninflected stems (both Fs < 1).

DISCUSSION

The striking finding of this investigation is that the patients tested, who have damage to the left peri-sylvian cortex and who show intact performance on timed and untimed measures of semantic processing, are delayed in activating the meaning of verbs when these have an overt past tense affix. The normal pattern of performance shown by age-matched controls, young volunteers (Longworth, Randall, et al., 2001), and elderly people (Longworth, Marslen-Wilson, & Tyler, 2002) is to show semantic priming for uninflected verbs and for both regular and irregular past tense forms. In contrast, the current patients showed priming only for verbs with simple morphophonology (e.g., uninflected stems and irregular past tenses) and not for the regular past tense, the only condition with overt affixation. This lack of priming for the regular past tense does not reflect a general failure to carry out the task as the patients made relatively few errors in primed lexical decision. It cannot be attributed to a general impairment of semantic processing, as the patients' priming for conditions in which prime words do not have overt affixes is indistinguishable from that of matched controls. This is in line with previous studies of semantic priming in anterior aphasics (e.g., Hagoort, 1997; Tyler, Ostrin, et al., 1995) and seems inconsistent with the view that such patients have reduced levels of semantic activation (e.g., Blumstein, 1997). In addition, the patients do not appear to have a general impairment of processing tense, as they show intact priming for irregular past tense forms and they have previously demonstrated spared morphological priming (Tyler, de Mornay-Davies, et al., 2002) and timed phonological judgments for irregular past tense forms (Tyler, Randall, et al., 2002).

We can rule out the possibility that these patients did not know the meaning of the verbs used in the regular past tense condition. First, their performance in semantic tasks is generally good (Tyler, de Mornay-Davies, et al., 2002). Second, we posttested their ability to rate the whole set of prime/target pairs as related or unrelated in meaning, without imposing time constraints. The patients performed at well above chance performance for uninflected stems, regular and irregular past tense forms with no significant differences between conditions. Thus, their semantic representations for the verbs used as regular past tense primes are not significantly impaired and they are able to access these semantic representations when given sufficient time and explicitly directed to focus on word meaning. However, they do not access them within the time frame in which either young (Longworth, Randall, et al., 2001), age-matched, or elderly volunteers (Longworth, Marslen-Wilson, et al., 2002) show semantic priming and within which they themselves show semantic priming from verb stems and irregular past tenses.

There is little evidence that the patients' deficit relates to the lack of perceptual salience of the past tense inflection (Joanisse & Seidenberg, 1999) or to the number of offset phonemes in regular past tenses (Bird et al., 2003). Post hoc analyses showed that the phonological properties of the prime words did not affect the degree of semantic priming shown by patients. In addition, because the patients showed intact semantic priming for verb stems, if their deficit related solely to perceiving the past tense inflection, they should have been able to access semantic representations from the embedded verb stems in regular past tense forms. Moreover, we have previously demonstrated that it is not the case that these patients necessarily show general phonological deficits (Tyler, Randall, et al., 2002). Patient AS, for example, performs at ceiling on several neuropsychological measures of phonological processing (see Tyler, Randall, et al., 2002). Thus, there is no consistent association between regular past tense deficits and general phonological impairments.

The patients' pattern of intact performance for uninflected verbs and the irregular past tense but abnormal performance for the regular past tense replicates the pattern found in both morphological priming (Tyler, de Mornay-Davies, et al., 2002; Marslen-Wilson & Tyler, 1997, 1998) and speeded phonological judgment tasks (Tyler, Randall, et al., 2002). Taken together, this research is consistent with dual-route accounts, which claim that the patients have a selective impairment of morphological decomposition (e.g., Ullman, Izvorski, et al., in press; Pinker & Ullman, 2002; Tyler, de Mornay-Davies, et al., 2002; Ullman, 2001; Ullman et al., 1997). The current study suggests that the patients' impairment disrupts automatic semantic activation for words in the regular past tense. It also rules out the possibility that the patients' previous pattern of performance for morphological priming and phonological judgments reflected a lexical repetition confound, with patients experiencing difficulty simply due to the immediate repetition of two very similar lexical forms. In this study, prime/target pairs are related in meaning and not form, but the pattern of results remains intact. The fact that patients can activate semantics from verb stems constrains the interpretation of their lack of regular past tense semantic priming, suggesting two possible interpretations of the findings. Adding a regular past tense inflection might cause phonological changes in the verb stem (e.g., vowel shortening) that disrupt the activation of its associated semantics for these patients. However, the fact that such patients clearly have difficulties distinguishing the phonology of regular stems and past tenses (Bird et al., 2003; Tyler, Randall, et al., 2002) suggests that they are not particularly affected by subtle phonological alterations of verb stems embedded in past tense forms. Instead, it seems more likely that a failure to parse a complex form into a stem and affix disrupts semantic activation for the stem, either by delaying or decreasing activation, or both, such that subsequent responses to related words are not primed. The fact that the patients could make untimed semantic judgments about the stimuli suggests that the disruption of semantic activation is transient. Thus, they might take longer than normal to access word meaning from inflected forms, rather than finding them wholly uninterpretable.

Dual-route accounts have claimed that the regular past tense comprehension deficits shown by patients with left peri-sylvian damage reflect a selective impairment in morphological decomposition (Ullman, Izvorski, et al., in press; Pinker & Ullman, 2002; Tyler, de Mornay-Davies, et al., 2002; Tyler, Randall, et al., 2002; Ullman, 2001; Ullman, Corkin, et al., 1997 Marslen-Wilson & Tyler, 1997, 1998, 2003), rather than a general phonological deficit (Bird et al., 2003; McClelland & Patterson, 2002; Joanisse & Seidenberg, 1999). The current results suggest that the patients have selective difficulties processing spoken regular past tenses, which disrupt the normally rapid time course with which word meaning is activated. This is consistent with dual-route accounts and, in particular, with the claim that comprehension of the regular past tense requires a process of morphological decomposition in order to access lexical semantics from the verb stem. Getting to the meaning of the regular past tense appears to require analysis of complex word structure and this can be disrupted by lesions to the left peri-sylvian cortex.

METHODS

Materials

This experiment is a modification of our previous semantic priming study (Longworth, Randall, et al., 2001) for use with neuropsychological patients (see Table 2 for examples of the stimuli used). We used 51 regular and 51 irregular verbs as semantic primes, divided into three balanced conditions of 34 items: uninflected verb stems, regular past tense, and irregular past tense. Where these items can be used as both verbs and nouns (e.g., *to blame*, *the blame*), we checked that they had higher frequency as verbs than as nouns in the Celex Lexical Database (Baayen, Piepenbrock, & Gulikers, 1995). We excluded suppletive verbs (e.g., *go/went, be/was*), because they are not representative of irregular verbs as a whole, and no-change irregular verbs (e.g., *to hit*) because their tense is ambiguous when presented as single words. Each verb prime was paired with a semantically related, uninflected verb that would be the lexical decision target.

As the aim was to use response facilitation to index semantic activation, it was important to ensure that prime/target pairs were sufficiently related in meaning and that facilitation was unlikely to reflect purely form-based associative relationships. Form-based associative priming occurs when the high co-occurrence of two words in the language leads them to facilitate responses to each other, irrespective of the degree of semantic relationship (e.g., *pillar* primes *society*, but is not related to it in meaning; Moss, Hare, Day, & Tyler, 1994).

Semantic Relatedness Pretest of Related Pairs

The semantic relatedness of all prime/target pairs was confirmed empirically by asking volunteers to rate this on a 9-point scale (1 = extremely unrelated, 9 = extremely related). Groups of 15 volunteers from the Centre for Speech and Language (CSL) pool (native speakers of UK English, aged 18–40, with no language disorders) rated the semantic relatedness of either the stem or past tense form of each verb prime paired with its target. Prime/target pairs were rated as being highly related in meaning (mean rating = 7.2, $SD = 0.7$) with no significant differences between conditions [$F(2,101) = 2.676, p > .05$].

Associative Strength Pretest of Related Pairs

Groups of 36–40 volunteers from the CSL volunteer pool pretested the forward associative strength of prime/target pairs. They were given booklets and asked to supply the first word they associated with each item. Forward associative strength was measured as the percentage of volunteers who gave the target as their first associate with the prime. The forward associative

Table 2. Descriptive Statistics for Experimental Stimuli

Conditions and Examples		*Semantic Relatedness/9*		*Forward Associative Strength to Target (%)*	*Word Frequency*[a]		*Length in Syllables*	
		Related	*Unrelated*		*Prime*	*Target*	*Prime*	*Target*
Verb stems *hope/WISH, weep/SOB*	Mean	7.4	1.8	7	56	38	1.1	1.4
Regular past *blamed/ACCUSE*	Mean	7.1	1.6	3	70	15	1.5	1.6
Irregular past *shook/TREMBLE*	Mean	7.0	1.6	4	46	19	1.1	1.4

[a]Frequency values from the Celex Lexical Database (Baayen et al., 1995).

strength between prime/target pairs was low overall (mean = 4.75%, SD = 7.1%) and there were no prime/target pairs that were related solely by association (i.e., with low ratings of semantic relatedness but high forward associative strength to targets). Stem prime/target pairs were more associated (mean associative strength = 7.11%, SD = 9.23%) than regular past tense prime/target pairs (mean associative strength = 2.79%, SD = 3.84%) (t = 2.49, df = 42.5, p = .017), but there were no significant differences between the regular and the irregular (mean associative strength = 4.37%, SD = 6.72%) past tense conditions (t = −1.2, df = 62, p = .25).

Semantic Relatedness Pretest of Unrelated Pairs

Unrelated prime/target pairs (e.g., *laugh/accuse*, *played/murder*) were formed by reordering related prime/target pairings while maintaining the verb regularity and tense of the primes. This ensured that there could be no systematic differences between related and unrelated primes in each condition other than semantic relatedness to targets. The semantic relatedness of these unrelated prime/target pairs was pretested in the same way as the related primes. Prime/target pairs in all three conditions were rated as being highly unrelated in meaning (mean rating = 1.7, SD = 0.6) with no significant differences between conditions ($F < 1$).

Semantic Relationship Posttest with Patients

We carried out a posttest subsequent to the priming experiment to check that the patients understood the semantic relationships between related and unrelated prime/target pairs. A lack of semantic priming would be uninformative if it simply reflected a general semantic impairment rather than disrupted semantic activation due to difficulties processing morphophonology. The patients were asked to rate the semantic relatedness of all related and unrelated prime/target pairs by pointing to a digit on a 9-point scale, on which 1 was marked "not very related" and 9 was marked "very related." Sadly, Patient MR suffered a second CVA before the time of testing and did not take part. The posttest confirmed that the patients had normal understanding of the semantic relationships between prime/target pairs. Patients AS and SD rated the related pairs significantly higher than the unrelated pairs [AS: mean rating of related pairs = 7.72; mean rating of unrelated pairs = 1.04; $F(1,31) = 521$, $p < .001$; SD: mean rating of related pairs = 8.63 mean rating of unrelated pairs = 1.16, $F(1,33) = 2327$, $p < .001$], with no significant differences between conditions [AS: $F < 1$; SD: $F(2,66) = 1.33$, $p > .05$]. Although Patient DE was unable to use the standard 9-point scale, he was able to provide binary ratings of related and unrelated pairs at well above chance performance (Related = 77% correct; Unrelated = 82%) and his ability to do so did not differ across conditions ($\chi^2 = 0.79$, $df = 2$, $p > .5$).

Regular and irregular past tense primes were matched for frequency as verbs according to the Celex Lexical Database (Baayen et al., 1995) as well as semantic relatedness and forward associative strength to targets (see Table 2). Items in the verb stem condition were matched as closely as possible to these past tense primes but reflect the fact that the uninflected prime/target pairs were rated as slightly more related. Target verbs were matched across conditions for frequency as verbs according to the Celex Lexical Database (Baayen et al., 1995). It was not possible to match the number of syllables in prime words across conditions and the regular past tense primes had slightly more syllables (mean = 1.47) than those in other conditions (stems: mean = 1.12; irregular past tense: mean = 1.09).

A range of filler items was selected to ensure that semantic relationships and inflected or uninflected verb primes could not be used to predict the lexicality of targets, thus reducing the possibility of strategic processing confounds. To this end, 208 unrelated noun/adjective prime/target pairs were included. Half of the nouns were used in the plural form so that inflected words did not predict a semantic relationship between primes and targets. Half of the targets in noun/adjective prime/target pairs were nonwords. One hundred four verb–nonword pairs were included with the same proportions of regular and irregular, stem and past tense primes as the experimental items. These ensured that verbs, both inflected and uninflected, did not predict either semantic relationships between primes and targets, or word targets. All nonword targets were uninflected and phonotactically legal. Their syllable length was similar to that of word targets (Words: mean length in syllables = 1.69, SD = 0.78; Nonwords: mean length in syllables = 1.52, SD = 0.56). All the items had been recorded by a female native speaker of English onto digital audiotape and digitized at a sampling rate of 22 kHz for our previous study (Longworth, Randall, et al., 2001).

The experimental materials were assigned to two versions of the experiment, with all targets appearing once in each version, preceded by either a semantically related or unrelated prime. Each version was subdivided into a practice session and four testing blocks. This allowed patients to rest between testing blocks. Prime/target pairs in each condition were balanced across versions and across testing blocks within versions, for the semantic relatedness of prime/target pairs and prime imageability, frequency, and length in syllables. The materials in each block were preceded by five warm-up trials.

Each version consisted of 458 trials: 24 practice trials, 20 warm-up trials, 51 related trials (17 verb stems, 17 regular past, 17 irregular past), 51 unrelated trials (17 verb stems, 17 regular past, 17 irregular past), and

312 filler trials. Semantically related experimental items made up 25% of word trials and 11% of the experiment as a whole. Experimental items and fillers were pseudorandomly distributed throughout each version with the same order of experimental and filler items in both. To avoid strategic responding, the pseudorandom ordering was constrained so that there were no sequences of more than three consecutive word or nonword targets and no sequences of consecutive trials from a single condition.

Procedure

Each participant was tested singly in a quiet room. They carried out both versions in the same order over two testing sessions, with at least 4 weeks between the two testing sessions to minimize the risk of episodic memory confounds. The stimuli were played binaurally to the patients and controls over headphones, under the control of DMDX experimental software (Forster & Forster, 2003). The participant's task was to judge whether each target was a word in English, as quickly and accurately as possible, using a response box with two buttons labeled "yes" and "no." Patient SD and control volunteers pressed the buttons with their index fingers, using their dominant hand to make "yes" responses. The three remaining patients, who have right-sided hemiparesis, used the index and middle fingers of their left hand to respond. There was a 284-msec interval between primes and targets and 3 sec in which to make a lexical decision response. After responding, the next trial followed in 1.5 sec. Response times were measured from target onset. The experiment lasted approximately one hour in total, allowing for rests between testing blocks.

Data Preparation

The data from four items, two from the stem condition and one each from the past tense conditions, were excluded from analysis due to high error rates in the patients (25% across participants), leaving a total of 98 items. For the analysis of response times, all lexical decision errors, namely, false rejections of words (patients: 1.28%; controls: 3.72%), were removed. The remaining response times were inverse-transformed (1000/RT) to correct a positively skewed distribution (Ratcliff, 1993) and mean response times were calculated over participants and items. For the analysis of response accuracy, the mean proportions of items correct were calculated over participants and items and arcsine transformed (2 arcsine $\sqrt{p}$ where p = proportion correct) (Winer, 1971). Response time and accuracy data were entered into separate analyses of variance on participant (F_1) and item (F_2) means. In analyses by participants, prime type (related or unrelated) and condition (verb stem, regular past tense, irregular past tense) were treated as within-participants factors and group (patients or controls) was treated as a between-participants factor. In the analyses by items, prime type and group were treated as within-item factors and condition was treated as a between-items factor. In all analyses, version (1–2) was included as an independent, dummy variable to stabilize variance due to the rotation of items over test lists. No main effects or interactions involving version are reported.

Acknowledgments

This research was supported by an MRC postgraduate research studentship and a University of Cambridge Pinsent–Darwin Research Fellowship to CEL, and an MRC program grant to LKT. We thank the patients for their participation. We also thank Michael Ullman and an anonymous reviewer for their comments.

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