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On the processing of regular and irregular forms of verbs and nouns: evidence from neuropsychology

Michele Miozzo

Department of Psychology, Columbia University, 1190 Amsterdam Avenue, New York, NY 10025, USA

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Abstract

Following acquired brain damage, a native English speaking patient (AW) encountered problems accessing phonology in speech production, while her ability to access word meaning appeared to be intact. In a series of tasks, AW was presented either with a verb, and was asked to produce its past tense or past participle (*walk* → "walked"), or with a noun, and was asked to produce its plural (*glove* → "gloves"). A stark dissociation was found: while AW responded accurately with regular forms of verbs (*walked*) and nouns (*gloves*), performance was significantly less accurate with irregular forms (*found*; *children*). The appearance of a selective deficit for irregular forms in conditions of impaired lexical access is in line with dual-mechanism accounts, which proposes that irregular forms are specified in the lexicon whereas regular forms are computed via rule-based mechanisms. In contrast, AW's data are problematic for connectionist accounts that do not posit separate mechanisms for processing regular and irregular forms, including the connectionist model recently proposed by Joanisse and Seidenberg (*Proceedings of the National Academy of Sciences USA 96* (1999) 7592) which successfully simulated a variety of earlier neuropsychological findings. Analyses of AW's responses shed light on further details of the representation and processing of regular and irregular inflected forms.

Keywords: Lexical processing; Lexicon; Morphology; Anomia

1. Introduction

In many languages, speakers modify the meaning of a word by changing the suffix appended to the end of the word. In English, for example, information about number (plural/singular) is conveyed by the presence/absence of the suffix -s at the end of nouns, and the suffixes -s, -ing, and -ed at the end of verbs express when the action or state described by the verbs takes place. Suffixation is an extremely productive process

E-mail address: michele@psych.columbia.edu (M. Miozzo).

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that speakers extend to recently introduced words like *fax* (*faxes*) and *e-mail* (*e-mailed*). But there are exceptions. English provides illustrative cases of such exceptions: a few plural nouns are not produced by adding the suffix -s (*teeth*, *women*, *fish*) and a good number of verbs take a past tense form that does not contain the suffix -ed (*ran*, *sat*, *went*). The occurrence of these irregular forms raises interesting questions about the process of word formation: are the mechanisms for word formation the same for regular and irregular words? If the mechanisms are not the same, how do they differ? Not only do the answers to these questions elucidate the organization of word formation processing (morphology) but they also have important implications for our understanding of the structure and functioning of the mental dictionary (the lexicon).

For the past 20 years, the debate about regular and irregular form processing has focused on English past tense inflection, which has become a crucial test case for theories of word formation. A view that has found wide support in linguistics and psycholinguistics is the dual-mechanism account, which holds that different mechanisms are at play with regularly inflected verbs (*walk–walked*, *argue–argued*) and irregularly inflected verbs (*run–ran*, *sit–sat*) (Bauer, 1983; Marslen-Wilson & Tyler, 1997; Pinker, 1991; Ullman, 2001). For regular past tenses, rule-based mechanisms add the suffix -ed to the verb stem (*walk* + ed → *walked*).[1] Irregular past tenses are not obtained via rule-based mechanisms, but are stored in the lexicon; consequently, to produce these irregular forms speakers have to access the lexicon. Because the process for producing regular and irregular past tenses follows different principles, it is likely that different areas in the brain support the processing of these verbs (on this point see e.g. Marslen-Wilson & Tyler, 1998).

A contrasting view holds that regular and irregular past tenses are computed by a single mechanism. This view was implemented in a number of connectionist simulations (e.g. MacWhinney & Leinbach, 1991; Marchman, 1993; Plunkett & Marchman, 1993; Rumelhart & McClelland, 1986). These simulations operate on the basis of associative mechanisms established through learning which link input nodes specifying the phonology of a verb stem (e.g. *walk*) to output units specifying the phonology of the verb's past tense (e.g. *walked*). The theoretical import of these simulations is twofold: they demonstrate that it is not necessary to postulate different mechanisms for regular and irregular past tenses, nor is it necessary to postulate rule-based mechanisms for the formation of regular past tenses.

In support of either of these views, researchers have cited various sorts of data: results from reaction time experiments, computer simulations, normal and abnormal language acquisition, and historical linguistics (for a review, see Clahsen, 1999; Marcus, 2000; Pinker, 1999; Ullman, 2001). Recently, in an attempt to gather data that may resolve the current debate as well as shed light on the brain mechanisms underlying word processing, researchers have turned their attention to brain-damaged patients with acquired language disorders. Ullman et al. (1997) tested patients with language impairments due to different pathologies in a past tense generation task. Patients were presented with a sentence like "Every day I dig a hole. Just like every day, yesterday I ____ a hole" and asked to complete the sentence by providing the past tense form of the verb, "dug" in this example. Discrepancies were observed in patients' abilities to produce regular vs. irregular

[1] In English, the -ed suffix is realized differently across words – e.g. /d/ in *bored* and /t/ in *baked*. Additional assumptions have to be made to account for such variations. I return to this issue in Section 5.

past tenses. Aphasic patients with posterior lesions and word-finding problems along with a group of patients diagnosed with Alzheimer's disease performed worse with irregularly inflected verbs. A contrasting pattern was reported for one aphasic patient with an anterior lesion and for a group of patients with Parkinson's disease; they encountered greater problems producing regular as opposed to irregular past tenses. Moreover, these patients performed differently than normal controls when asked to generate the past tense of novel verbs (*vask*, *tunch*): while normal controls typically added the suffixed -ed ("vasked", "tunched"), the patients did so far less frequently. Similar dissociations have now been observed in a variety of tasks. Marslen-Wilson and Tyler (1997, 1998) have documented selective deficits in the comprehension of regular or irregular past tenses with the priming paradigm. Four patients with acquired language deficits heard two words (a prime and a target) and decided whether the second word corresponded to a familiar word. Various prime–target pairs were used: morphologically related (*jumped–jump*), semantically related (*swan–goose*), and unrelated (*locked–jump*). For two patients, priming (faster responses than those for unrelated pairs) appeared in the presence of pairs formed by semantically related words and by irregular past tenses (*found–find*). For two other patients, facilitation only appeared in the presence of regular past tenses (*walked–walk*). Similar dissociations have been observed in reading (Ullman et al., 1997, in press), and in a judgment task in which patients were asked to rate the 'goodness' of correct and incorrect past tense forms (e.g. dug/digged, rob/rob; Ullman et al., in press). In sum, the dissociation documented between regular and irregular past tenses both in speech production and comprehension has been interpreted as supporting the principle claim of the dual-mechanism account: that regular and irregular forms are processed by distinct (and neuroanatomically segregated) mechanisms (see also Bullinaria & Chater, 1995). The neuropsychological data have been considered to be incompatible with the view, endorsed by single-mechanism theories and implemented in connectionist networks, that regularly and irregularly inflected verbs recruit identical processes.

Joanisse and Seidenberg (1999) challenged the claim that the neuropsychological evidence is irreconcilable with models that do not incorporate distinct processes for regular and irregular inflections. They implemented a connectionist model that simulated different tasks with past tenses, including the elicitation task devised by Ullman et al. (1997). The model includes units devoted to the encoding of verb meaning[2] and verb phonology, respectively (see Fig. 1). The model also incorporates separate phonological units for speech input and speech output. A key feature of the model is that regular and irregular past tenses are processed similarly, in the sense that identical mechanisms are implicated in the processing of both classes of verbs. This feature does not mean that semantic and phonological information are equally critical for the production of regular, irregular, and novel past tense forms. Because a novel verb like *wug* does not have any meaning, semantic information cannot contribute to the generation of the past tense form of *wug*, which has to be derived "by analogy" from the phonology of known verbs. In contrast, semantic information is crucial for irregularly inflected verbs; the generation of

[2] The designation of semantic for one level of nodes is an arbitrary one as these nodes have no "semantic content" that would require one to call them "semantic" rather than, let's say, "lexical" (similar criticisms were raised by Pinker, 2001). For each verb there is a single node that supposedly encodes the verb's semantics.

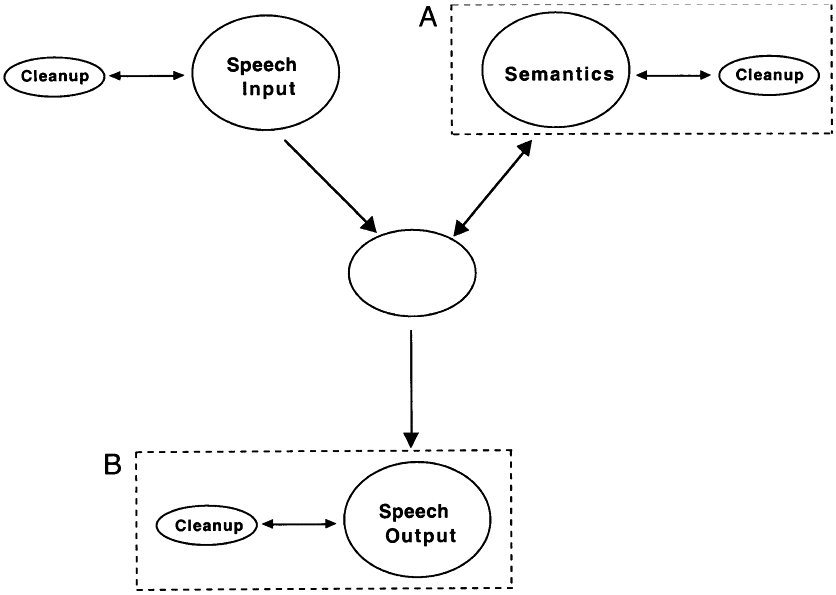

Fig. 1. Schematic illustration of the computational model implemented by Joanisse and Seidenberg (1999). To simulate the present tense → past tense generation task, the phonological code of a verb stem was given as speech input and the past tense semantics was activated; the model provided the phonological code of the verb's past tense in speech output. The "lesion" of the components in boxes A and B differently affected the retrieval of the past tense forms of regular, irregular, and novel English verbs.

their past tense form depends on the establishment of a link between their semantic representation and their representations in both input and output phonology. In this way, the past tense of irregularly inflected verbs will not conform to the statistically dominant pattern. To simulate the neuropsychological data, Joanisse and Seidenberg (1999) selectively damaged different components of their connectionist model. Damage to the semantic units impaired the generation of regular, irregular, and novel past tenses, but the largest impairment appeared with irregular forms. Damage to the phonological units also affected the processing of all three types of verbs,[3] but novel verbs were impacted most severely. Joanisse and Seidenberg (1999) were therefore able to reproduce (at least part of) the dissociations reported in neuropsychology with regular, irregular, and novel past tenses. The fact that these dissociations emerged in a connectionist network that does not explicitly incorporate specific mechanisms for regular and irregular inflections calls into question the claim that the neuropsychological data are incompatible with this sort of model. Of course, the ability to replicate the neuropsychological dissociation comes with an added cost: semantics is called upon for the processing of the regular/irregular verb distinction that has traditionally been considered an idiosyncrasy of language with

[3] It should be noted that selective lesions of semantic or phonological units had widespread effects in the model: for all verbs (regular, irregular, and novel) the correct rate was lower in damaged vs. intact systems. This is an important aspect of the model and will be discussed later in the paper.

relevance only for language processing. By contrast, the dual-mechanism account supports the opposing view that the regular/irregular verb distinction is confined to the realm of language processing.

The computational simulations reported by Joanisse and Seidenberg's (1999) also have implications for our understanding of the deficits that have been observed in neuropsychology with English past tenses. In particular, deficits selectively or more severely impacting irregular past tense processing should be associated with damaged semantics. The expectation is then to find a deficit for irregular past tenses in patients with impaired semantics, but not in patients with impaired phonology. Indeed, Joanisse and Seidenberg (1999) speculated that the deficit for irregular inflections that Ullman et al. (1997) reported in their patients might have resulted from a semantic impairment. These patients present with posterior aphasia and Alzheimer's disease, cognitive deficits that are frequently accompanied by semantic impairment. The consequences of damaged semantics have been assessed by Patterson, Lambon Ralph, Hodges, and McClelland (2001) in a group of patients with semantic dementia, a form of progressive memory and language disorder that affects semantic knowledge in particular. Patients performed significantly worse with irregular verbs than regular verbs in the past tense generation task (Ullman et al., 1997) and in a recognition task in which patients chose the correct form between two alternatives (*bought/buyed*, *saved/sove*). Patients' accuracy in both tasks correlated with their knowledge of verb meaning as shown by a synonym judgment task in which patients were asked to identify verbs with similar meanings (e.g. for *grind* the correct response would be *crush*, not *sip*). Taken together, the Patterson et al. (2001) data suggest a causal link between a semantic deficit and a deficit for irregular inflections and thus provide support to the Joanisse and Seidenberg's (1999) account. This conclusion is strengthened by the observation that the two patients reported by Marslen-Wilson and Tyler (1997, 1998) with a selective deficit for irregular past tenses did not show semantic priming, a finding which leads one to suspect the co-occurrence of a semantic deficit in these patients. Finally, further converging evidence comes from a study conducted by Tyler, deMornay-Davies et al. (2002) on four patients with semantic deficits due to left inferior temporal gyrus damage following herpes simplex encephalitis. As a group, the patients were impaired in their ability to produce irregular past tenses in an elicitation task similar to that of Ullman et al. (1997).

A selective deficit for irregular past tenses receives a different explanation within the dual-mechanism account: this deficit is likely to follow a problem in processing lexical information (instead of a semantic impairment). It should be recalled that in the dual-mechanism account, the phonological forms of irregularly inflected words are stored in the lexicon, and problems in retrieving the phonological forms from the lexicon should lead to difficulties particularly with irregularly inflected words. In theory, there are multiple ways in which the dual-mechanism models could account for the co-occurrence of deficits for semantic knowledge and irregular past tenses. Marslen-Wilson and Tyler (1998) provided an articulate account of why, in a comprehension task, semantic processing and the processing of irregular past verbs were both impaired. At base, dual-mechanism models are committed to the prediction that patients with *selective* problems of lexical access should fail with irregular verbs.

Anomia, an acquired speech deficit characterized by patients' difficulties finding the correct word, offers a further opportunity to test the dual-mechanism account and the single-mechanism account implemented by Joanisse and Seidenberg (1999). The speech of anomics is fluent and (at least in some patients) grammatical, though punctuated by frequent pauses in which they struggle to find the desired word (Allport, 1983; Garrett, 1992; Geshwind, 1967; Kay & Ellis, 1987). Anomics' speech failures relate to a problem of retrieving the word phonology stored in the lexicon, either because this information has been lost or is not accessible. Anomics may occasionally succeed in reporting fragmentary information about the sound of the target word – its onset phoneme(s), or words that sound like the target word (see e.g. Henaff Gonon, Bruckert, & Michel, 1989) – but in many cases the word phonology remains unavailable (see e.g. Badecker, Miozzo, & Zanuttini, 1995). Information about the syntactic features of words that is stored in the lexicon (grammatical class, number, verb aspect, etc.) may or may not remain available to anomic patients. In some anomics, semantic processing appears to be intact, as demonstrated by the fact that, for example, the patients can provide accurate descriptions or synonyms of the words they fail to produce. The dissociation found in anomia between intact semantic processing and impaired phonological retrieval is of particular relevance here.

In production tasks in which verb stems have to be retrieved from the lexicon (e.g. in naming depicted actions) anomics should be equally impaired with regular and irregular verbs, as long as these verbs are matched for variables known to affect anomics' naming (e.g. word frequency). However, differences between regular and irregular forms are expected in the stem → past tense generation task (Ullman et al., 1997). More importantly, the dual-mechanism account and the Joanisse and Seidenberg's (1999) account make contrasting predictions about how patients with anomia (but no semantic damage) will perform in tasks of regular and irregular past tense production. The dual-mechanism account anticipates a deficit in the production of irregular past tenses. Because anomics have problems retrieving the forms stored in the lexicon, and because the forms of irregular past tenses have to be retrieved from the lexicon, the generation of irregular past tenses should be impaired. As long as rule-based mechanisms are intact, and the *-ed* suffix can be retrieved successfully, anomics should be able to add the *-ed* suffix to the stem, and thereby respond correctly in instances in which they are asked to produce regularly inflected verbs and novel verbs. With respect to the Joanisse and Seidenberg's (1999) model, their simulations of phonological damage recreate the conditions observed in forms of anomia not associated with a semantic impairment; the expectation is to replicate in anomia the pattern that is observed in the model with damaged phonology. Namely, we should find that anomics are, relative to normal controls, impaired with regular, irregular, and novel past tenses. Moreover, anomics should perform equally well with regular and irregular past tenses, and better with these verbs than with novel verbs.

Patients classified as anomics were reported by Ullman et al. (1997, in press), but unfortunately this study did not include analyses of patients' semantic processing. Currently we do not know how anomics with spared semantics process regular, irregular, and novel past tenses. It is this issue that is addressed in the present paper. Here I report an in-depth investigation of AW, a brain-damaged English-speaking patient with acquired anomia, and describe her ability to process regular, irregular, and novel verb inflections. Because English also includes nouns that are irregular in their plural form (e.g. *women*, *deer*, and *oxen*), AW's production of regular and irregular plural nouns was also examined to see whether similar deficits emerge with nouns and verbs. The presentation of the patient's data is divided into two parts: the first part documents AW's word-finding difficulties and shows that AW's semantic processing is intact; the second part describes how AW produces inflected forms of familiar and novel verbs, and nouns.

2. Patient description

AW is a native English speaker and a housewife with a high-school education. She is right handed with no familial sinistrality. The patient reported not having close relatives suffering from degenerative dementia, schizophrenia or developmental learning disorders such as dyslexia. At the time of testing she was 71, and had suffered a stroke 2 years earlier. A brain CT scan taken 3 days after her stroke showed lesions of the basal ganglia, the frontal white matter, and of the medial and superior temporal areas. Fig. 2 shows the extent of the temporal damage.

The language screening battery administered routinely in our laboratory indicated intact auditory word recognition, as AW was able to discriminate whether two words were identical or differed by one phoneme (40/40 correct). She showed good comprehension of sentence grammar, as she correctly matched a short sentence (e.g. "the man is chasing a bull") to its corresponding picture rather than to a foil picture (e.g. of a bull chasing a man) (15/16 correct; controls' range 15–16). Grammatical processing also seemed intact for word production, as AW correctly completed sentences (10/10 correct) and no grammatical errors were evident from transcripts of her spontaneous speech. In addition to a word production impairment – which I discuss below – the following deficits in reading, spelling, and verbal short memory were recorded.

2.1. Reading

AW correctly named 13 upper-case letters and 12 lower-case letters of the English alphabet. She was impaired in reading aloud words (17/20, 85% correct) and nonwords (11/20, 55% correct). Her errors consisted of additions, deletions and substitutions of one or more letters (e.g. *stint* → /sint/, *camel* → "camera", *elbow* → "elevator"). Errors were more frequent with words that have irregular rather than regular spelling/sound mapping (24/36, 66% vs. 31/36, 86%; this difference approaches significance: $\chi^2 = 2.77$ (Yate's correction applied), $P < 0.10$; words from Johns Hopkins Dyslexia Battery). AW's ability to discriminate between familiar and novel words was intact (10/10 correct responses), as was her ability to access meaning from written words (she successfully matched 20 written words to their pictures rather than to semantically related foils).

2.2. Spelling

In writing to dictation and in oral spelling, 5/10 words were spelled incorrectly; examples of errors include *mask* → mast, *candle* → camel, *scissors* → sission.

2.3. Verbal short-term memory

Like the anomic patient reported by Martin, Lesch, and Bartha (1999), AW demon-

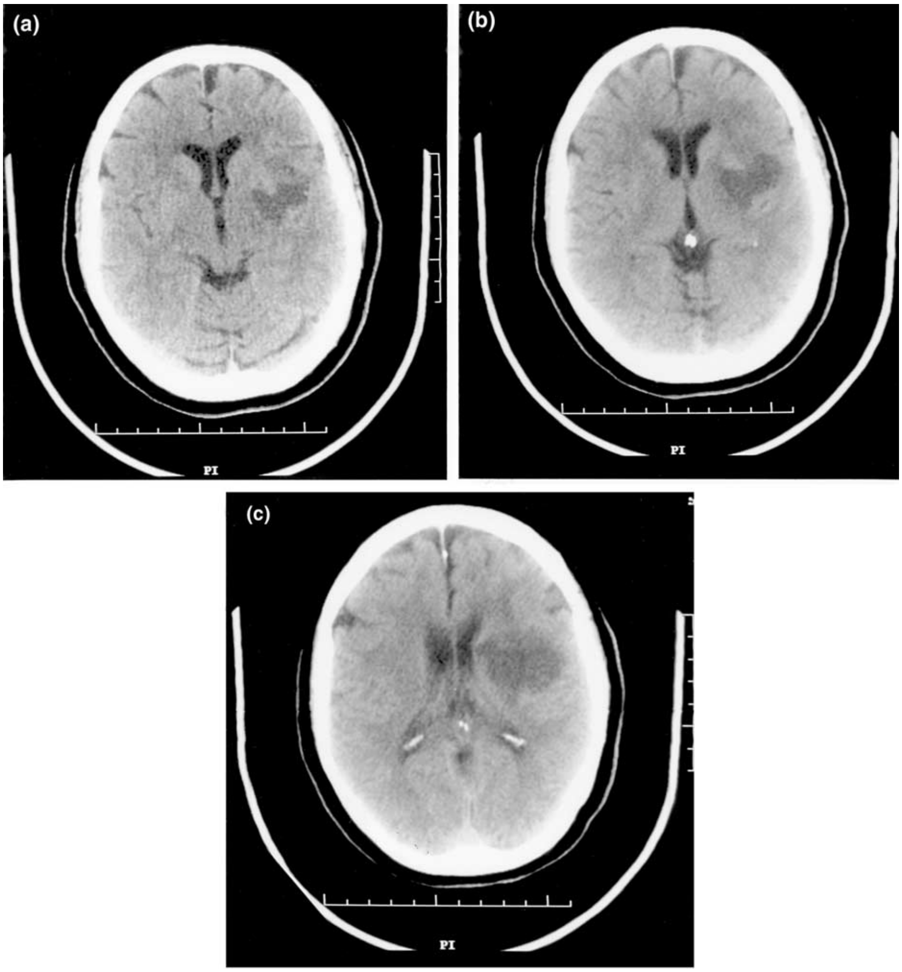

Fig. 2. Brain CT scan of AW's lesion.

strated limited verbal short-term memory: she was unable to repeat in the forward direction and in the right order strings composed of more than three digits.

3. Part 1: lexical vs. semantic impairment

The results presented in this section establish that the word-finding difficulties observed in AW arise as a consequence of her problems retrieving word *lexical* phonology, that is information about the phonology of the word that is stored within the lexicon. Such information specifies the phonemes and other features of the word (e.g. stress, number of syllables) that are critical for the correct realization of the word. By contrast, phono-

Table 1
Oral picture naming task: examples of AW's responses

Picture	AW's response
Glove	"Sleeve, no for the hand… glove"
Ostrich	"A bird… but I do not remember the name…"
Microscope	"You look through this"
Dice	"Dominoes, no it has another name… I can't say now"
Sailor	"Tailor… no… he is in the army…"
Bride	"…/blaid/… b-r-i-d-e, bride"
Hammer	"/kAmen/, no I mean hammer"
Frog	"Owl… no… green [the picture was not colored] jumps… does it start with /h/? Hog? No it's not a hog… I can't say"

logical processes that take place after the retrieval of lexical phonology and processes that involve articulation seem to be preserved. The results presented in this section also demonstrate that AW's access to word meaning is preserved.

3.1. Picture naming

To assess her word-finding difficulties, AW was asked to orally name pictures from different sources (Boston Naming Task: Goodglass & Kaplan, 1972, $N = 50$; Snodgrass & Vanderwart, 1980, $N = 203$; Philadelphia Naming Task: Roach, Schwartz, Martin, Grewal, & Brecher, 1996, $N = 175$). AW's responses were often laborious: she would begin by describing the picture or by providing words related in meaning or sound to the picture name, words that she ultimately discarded as incorrect; occasionally these initial attempts led her to retrieve the correct noun. Examples of her responses are shown in Table 1. Because of her repeated attempts, the last response was scored. AW's correct naming rate varied across picture sets, ranging between 62% and 86% (see Table 2). The majority of errors consisted of omissions, i.e. failures to produce a response that the patient, herself, accepted as correct. On only three occasions did AW produce a semantically related name (*candle* → "lantern", *toothbrush* → "toothpaste", *harp* → "violin"). One error was phonologically related (*canoe* → /kamon/), and another error was phonologically and morphologically related (*ruler* → "ruling"). The error *zipper* → "scissors" is not easily classifiable – perhaps it represents a visual confusion, as the picture of the *zipper* that was

Table 2
Oral picture naming task: AW's responses

Picture set	*N* pictures	Responses (*N* (%))	
		Correct	Omissions
Boston Naming Test	50	31 (62)	18 (36)
Snodgrass and Vanderwart	203	175 (86)	26 (13)
Philadelphia Naming Test			
First administration	175	139 (79)	33 (19)
Second administration	175	144 (82)	31 (18)

used vaguely resembles a pair of scissors. Post-hoc analyses revealed that the frequency of the picture name affected the accuracy of AW's naming responses. Frequency (as measured in Francis & Kucera, 1982) was significantly higher for correct responses than it was for incorrect responses (mean 60 vs. 19; *t*-test, $P < 0.001$), a discrepancy that has also been reported in other patients with word-finding difficulties.

Three other aspects of AW's naming responses are of particular interest. The first concerns the accurate descriptions that AW consistently provided even for those pictures that she failed to name. For example, for *scarf* she said "you put it around the neck", and for *pyramid* she said "you find it in Egypt". These descriptions suggest that AW can access a fairly accurate representation of the picture meaning. The second aspect of interest here is that while attempting to produce a name, rarely would AW produce phonologically related words or nonwords (*tractor* → /trakle/, *towel* → "table") or fragments of the target word (*sock* → /sa/). This latter observation suggests that AW has limited access to the phonology of the word stored in the lexicon, which may lead her to fail to produce a response (omission). Finally, it is interesting to note that AW's responses were phonologically well formed.[4] The latter result suggests that 'late' phonological processes that follow the retrieval of lexical information and involve syllabification and prosodification as well as articulatory processes are intact. In the next two experiments, we present additional results showing AW's failure to retrieve word phonology, while 'late' phonological and articulatory processes remain intact.

3.2. Access to word phonology

To determine the extent to which word lexical phonology was available to AW when she failed to orally name a picture, AW performed a series of forced-choice recognition tasks. In each task, AW was asked to recognize a different phonological feature of the word that was inducing the omission response:

(a) onset consonant (e.g. "Does the name of this picture [stool] start with /s/ or /t/?");

(b) syllable number (e.g. "Does the name of this picture [trumpet] have one or two syllables?");

(c) rhyming word (e.g. "Does the name of this picture [bear] rhyme with chair or hand?");

(d) indefinite article (e.g. "Does the name of this picture [elephant] take the article an or a?").

Different sets of pictures were employed in each task. Whenever an omission occurred, and while AW was in the process of seeking the target name, the experimenter asked AW to select one of two alternatives. As can be seen in Table 3, AW performed poorly: in all four tasks, her correct recognition rate was not significantly different from that of chance (50%) (χ^2s ≤ 2, N.S.). Brain-damaged patients with language impairment have been reported to encounter problems in identifying phonological features such as those queried in the present task (McCarthy & Warrington, 1990). To determine if this is the reason why AW failed in this task, she participated in a second task in which a target name was

[4] AW also produced well formed words in speech context. For example, no phonological distortions were detected in the oral definitions that AW provided for 35 concepts.

Table 3
Forced-choice recognition task: AW's *N* (%) correct responses

Phonological feature	*N*[a]	*N* (%) correct responses/total – stimuli[b]	
		Pictures	Oral names
Onset consonant	46	24 (52)	46 (100)
Syllable number	38	16 (42)	33 (87)
Rhyming word	20	10 (50)	20 (100)
Indefinite article	19	6 (31)	16 (84)

[a] These were responses in which AW failed to name a picture and the experimenter orally presented two alternatives. The total number of responses equals the number of naming failures observed in the task with a larger number of pictures.
[b] The picture name and the two alternatives were orally presented by the experimenter.

presented auditorily and she chose the target feature between two alternatives. AW performed well in the latter task (94% correct), a result that rules out a problem in identifying the phonological features queried in the task. Taken together, the tasks presented in this section reveal that AW's access to the lexical phonology of the words she failed to name was poor.

3.3. Word repetition

The information about word phonology that is retrieved from the lexicon is the input for syllabification and prosodification processes, the latter providing the input for articulatory programs. If AW's naming problems derive from a deficit of speech processes that follow the retrieval of lexical phonology, then the patient should encounter difficulties in repeating an auditorily presented word. To test this possibility, AW repeated the nouns of 144 pictures presented in the naming task. AW correctly repeated all the nouns, ruling out the possibility that the source of her naming difficulties can be traced to the level of 'late' phonological or articulatory processes.

3.4. Access to word semantics

The fact that AW provided precise semantic information about the pictures that she could not name leads one to suspect intact access to semantics. This hypothesis was investigated more directly in a series of matching tests. Studies have shown that patients with mild semantic deficits are impaired in tasks demanding access to detailed semantic description of a concept, whereas they may perform flawlessly in tasks that only ask coarse semantic information, such as picture-categorization tasks (e.g. Hillis & Caramazza, 1995; Miozzo & Caramazza, 1998). In line with these findings, the tasks administered to AW demanded access to specific semantic features. It is reasonable to assume that such features are part of the knowledge that speakers have about word meaning. Thus, the data presented in this section not only shed light on AW's conceptual knowledge in general but also on her ability to access word meaning.

3.4.1. Picture–picture matching tasks

In two tasks, the patient saw three semantically related pictures (a probe and two alternatives). The tasks require that the patient chooses the alternative that is more closely related to the probe. For example, for *web* the alternatives were *spider* (the target) and *ant* (the foil). One task was from Hillis and Caramazza (1995), the other from the BORB (Riddoch & Humphreys, 1993). AW responded flawlessly and was correct in 32/32 (100%) trials in the first task and in 29/30 (97%) trials in the latter one.

3.4.2. Picture–description matching task

One hundred and four pictures from Snodgrass and Vanderwart (1980) which had been named earlier by AW were shown in this task. For each picture the experimenter read two brief sentences. One sentence (true) described a feature of the depicted object, the other sentence (false) described a feature that seems plausible but is indeed incorrect. AW's task was to indicate which sentence was true and which was false. For example, for *fly*, the true sentence is "Does it buzz?" whereas the false sentence is "Does it hop?". The test inquires about features not depicted in the pictures. AW's responses were invariably correct (208/208). In the earlier task, AW had failed to name 14 pictures shown in the picture–description matching task. It is interesting to note that even for these pictures, AW responded correctly.

AW's excellent performance in tasks demanding access to detailed semantic descriptions indicates intact semantic processing and is inconsistent with the hypothesis that a semantic deficit underlies AW's word-finding difficulties.

3.5. Access to verb semantics

Given that verbs are the focus of the present investigation, it is important to assess the status of AW's semantic representation of verbs. To this end, a new version of the forced-choice synonym judgment task devised by Patterson et al. (2001) was prepared. On each trial, the experimenter said a probe verb (e.g. *to walk*) and two alternatives; one alternative was an approximate synonym verb (*to stroll*), and the other alternative was a verb slightly more distant in meaning (*to run*). AW's task consisted of choosing the approximate synonym verb. The probe verbs were the 100 verbs selected for the first of the past tense generation tasks presented below. The patient responded correctly on 98/100 (98%) of the items, a rate comparable to that obtained from five normal controls[5] (mean 98%). AW's good performance in this task invites the conclusion that AW has no problems in accessing the semantics of verbs.

3.6. Summary

The results reported in this section converge to support the conclusion that AW's naming deficit arises because of a problem of lexical retrieval, specifically one of retrieving word phonology, while the phonological processes that follow lexical access as well as articulatory processes appear to be preserved. Additional, though more anecdotal,

[5] All the normal controls tested in this study were people comparable to AW in age (71 ± 4 years) and education (high school degree).

evidence that lexical phonology is not available to AW was obtained in reading. As mentioned in Section 2, AW is severely impaired in reading words and nonwords. Interestingly, a number of “stress errors” like *degree* → “dègree” or *forbid* → “fòrbid” were observed, in which the sounds of the individual letters were correctly realized but the main stress fell on the wrong syllable. “Stress errors” occurred predominantly with English two-syllable words that have an irregular stress pattern – that is, words in which the primary stress falls on the second syllable. “Stress errors” have been reported in other patients with problems of lexical retrieval in speaking (Cappa, Nespor, Ielasi, & Miozzo, 1997; Miceli & Caramazza, 1993) and reflect the unavailability of information regarding stress placement, information that for words with an irregular stress pattern is supposedly stored at the lexical level. In contrast, AW seems able to access the meaning of words, as demonstrated by the accurate descriptions that she would occasionally offer to describe the pictures she failed to name and, more formally, by her flawless performance in tasks demanding access to detailed semantic representations of nouns and verbs. Although such evidence does not allow one to rule out, with absolute certainty, a very subtle semantic impairment, it does make it quite probable that AW’s access to word meaning remains intact.

4. Part 2: generation of regular vs. irregular forms

This section presents several tasks that compare AW’s ability to generate regular and irregular verbs and nouns. The issue is whether AW, a patient with problems in retrieving word lexical phonology, shows selective deficits in producing regular or irregular forms. Another task requires AW to generate the past tense of novel verbs and is intended to determine whether the patient applies regular inflections to these verbs.

4.1. Past tense generation task – with sentences

This is a modified version of the Ullman et al.’s (1997) task and requires the patient to complete a sentence by producing the past tense of a specific verb. For example, for the sentence “Everyday I walk to the store; yesterday I ____ to the store” the expected response was “walked”. Sentences were read aloud by the experimenter and were all composed of the same subject (“I”) and of the same adverbs (“everyday” and “yesterday”) so as to facilitate sentence comprehension and to circumvent AW’s limited short-term memory capacity. Sentences were repeated at the patient’s request. The first response was recorded (the procedure outlined here holds for all the tasks presented in Part 2). There were 209 sentences in total and target verbs were distributed as follows: 100 verbs with regular past tense (e.g. *walk–walked*), 100 verbs with irregular[6] past tense (e.g. *buy–bought*), and nine ultra-high frequency verbs with irregular past tense (e.g. *go–went*). Different types of irregular past tense forms have been selected. These forms were classified with reference to the change between the citation form and the past tense form as follows: vowel change (as in eat → ate; $N = 65/100$), consonant change (as in make → made; $N = 7/100$), vowel + consonant change (as in lose → lost; 15/100), and no change

[6] In American English, some verbs have more than one irregular past tense form: an example is *shrank/shrunk*. Each of these forms was scored as correct (this holds for the task with past participle verbs as well).

Table 4
Verb generation task: *N* (%) correct responses (AW and controls)

Past tense generation task	*N* correct/total responses (%) – inflection	
	Regular	Irregular
Past tense, with sentences		
First administration	99/100 (99)	80/100 (80)
Second administration	98/100 (98)	63/100 (63)
Past tense, without sentences	91/95 (96)	68/95 (71)
Controls		
Mean	93/95 (98)	91/95 (96)
Range	92–94	90–92
Past participle, without sentences		
First administration	96/97 (99)	57/97 (59)
Second administration	96/97 (99)	62/97 (64)
Controls		
Mean	96/97 (99)	94/97 (97)
Range	96–99	94–95

(as in hit → hit; $N = 13/100$). A frequency control is necessary given that this variable affects AW's responses. The two groups of verbs were matched for lemma (stem) frequency – i.e. the sum of the number of occurrences of all the forms of a given verb (e.g. to walk + walk + walks + walking + walked) as listed in Francis and Kucera (1982) (mean: regular 140, irregular 147; $t < 1$). The verbs were also matched for the frequency of their past tense forms (surface frequency; mean: regular forms 31, irregular forms 35; $t < 1$). Ultra-high frequency irregular verbs have an extremely high lemma frequency (mean 1220) and past tense frequency (mean 360). Materials were presented in a random order. Controls' data were not collected for this task but only for the next task. (It is very likely that controls would perform at ceiling in this task as they did in the next task which employed similar materials.)

The task was repeated twice, 2 months apart. On each administration, a striking dissociation emerged between regular and irregular past tense verbs (see Table 4): for regular past tenses, AW's correct rate was nearly perfect (99% and 98%), whereas for irregular past tenses, it was significantly lower (80% and 63%; χ^2s = 19.2 and 39.0, *P*s < 0.001). Three errors were observed with the ultra-high frequency irregular verbs (*go* → "go", *think* → "think", *make* → "maked"). The fact that errors appeared with very frequent verbs as well further attests to the severity of AW's deficit with irregular past tense forms. A qualitative analysis of AW's errors on this task (as well as on the others) will be presented later in the section.

4.2. Past tense generation task – without sentences

This task provides a further attempt to assess how AW generates the past tense of regular and irregular verbs. The experimenter said the present tense of a verb ("walk", "cut", "drink") and AW was asked to generate its past tense ("walked", "cut", "drank"). There were 95 verbs with the regular past tense form and 95 verbs with irregular past tense forms, matched for lemma frequency (mean 166 and 167, respectively; $t < 1$) as well as for the frequency of their past tense forms (mean 39 and 42, respectively; $t < 1$). The majority of verbs with irregular forms (92/95) and with regular forms (76/95) were also used in the preceding test with sentences. Irregular past tenses were distributed as follows: vowel change (as in eat → ate; $N = 61/95$, 64%), consonant change (as in make → made; $N = 7/95$, 7%), vowel + consonant change (as in lose → lost; 14/95, 15%), and no change (as in hit → hit; $N = 13/95$, 14%). The three controls performed at ceiling with regular forms (98% correct) and with irregular forms (96% correct) and χ^2 tests run for each individual subject revealed no significant differences ($P < 0.05$) between these verbs. AW's accuracy rate for regular past tenses (91/95) is comparable to that of controls (range 92–94). However, AW performed significantly worse with irregular than with regular past tenses (96% vs. 71% correct; $\chi^2 = 20.3$, $P < 0.001$).

4.3. Past participle generation task – without sentences

In English, the past participle of some verbs is not obtained by adding the suffix -ed. Examples of irregularly inflected past participles include *speak–spoken*, *write–written*, *hit–hit*. As in the preceding task, the experimenter read aloud a verb's stem and AW was asked to produce its past participle. The past participle was regular for half of the verbs ($N = 97$) and irregular for the other half. The lemma frequency of regular and irregular forms was comparable (mean 144 and 155, respectively; $t < 1$) as was the frequency of their past participles (mean: regular 29, irregular 28; $t < 1$). Like past tenses, irregularly inflected past participles can also be classified with respect to how their phonemes differ from those of their stems. According to these criteria, the irregular past particles used in the experiment were distributed as follows: vowel (as in dig → dug; $N = 37/97$, 38%), consonant change (as in bend → bent; $N = 6/97$, 6%), vowel change + consonant change (as in sell → sold or beat → beaten; 41/97, 42%), and no change (as in hit → hit; $N = 13/97$, 13%). As in the previous task, controls performed at ceiling with both types of forms (regular 99%, irregular 97%) and χ^2 tests revealed no statistically significant ($P < 0.05$) differences for any of the controls. The task was administered to AW twice, 1 month apart. On both administrations, AW performed as controls with regularly inflected forms (99% correct; see Table 4); however, she performed worse with irregularly inflected forms[7] (59% and 64% correct; χ^2s = 47.0 and 39.4, Ps < 0.001).

4.4. Response analyses

The errors observed with the *irregular* inflections in the various tasks were classified following the criteria defined in earlier neuropsychological studies as: (a) regularizations

[7] It has been proposed that past participles like *blown* or *broken* are compositional forms obtained by appending -(e)n (Halle & Marantz, 1993). If this intuition is correct, AW should successfully produce the past participle of these verbs. However, for these verbs the correct responses were 8/27 (30%; first administration) and 15/27 times (55%; second administration).

Table 5
Distribution of AW's errors with irregular past tenses and past participles

Error type	*N* (%)			
	Past tense		Past participle	Total
	With sentence	Without sentence		
Regularizations	22 (39)	8 (30)	23 (30)	53 (33)
fall → "falled"				
run → "runned"				
Double marked errors	5 (9)	0 (0)	3 (4)	8 (5)
bind → "bounded"				
stride → "stoded"				
No change	14 (24)	9 (33)	18 (24)	41 (26)
feel → "feel"				
hold → "hold"				
Irregular-like forms	9 (16)	5 (19)	26 (35)	40 (26)
sink → "sunk"				
flee → "flung"				
-s addition	4 (7)	2 (7)	2 (3)	8 (5)
beat → "beats"				
hurt → "hurts"				
Omissions	3 (5)	3 (11)	3 (4)	9 (5)
N	57	27	75	159

(verb stem + ed, as in *fall* → "falled"); (b) double marked errors (as in *stride* → "stroded"); (c) irregular-like forms, in which one or more consonants and/or vowels of the verb stem are changed (as in *flee* → "flung"); (d) no-change (as in *feel* → "feel"); (e) addition of the suffixes -s (as in *beat* → "beats"); (f) omissions (failures to produce a response). There were no instances in which AW added the suffix -ing to the stem (as in *think* → "thinking"). Because the errors were similarly distributed across tasks, as can be seen in Table 5, it was decided to analyze the errors together. It is worth noting that only 33% of AW's errors with irregular inflected verbs were regularizations; the remainder of her errors consisted mostly of responses that resembled irregular forms, either because AW produced the stem form (26% of the time) or because she changed one or more phonemes of the present tense (26% of the time). This pattern suggests that AW did not approach the past tense and past participle generation tasks using a strategy that consisted of appending the suffix -ed to the end of the verb stem. Such a strategy would explain why AW was invariably correct with regular inflections but would also predict that AW's errors with irregular inflections would consist primarily of regularizations. The appearance of a number of errors like *eat* → "eat" or *slide* → "slode" rules out the hypothesis of an indiscriminate use of an "add -ed" strategy by AW.

Concerning the nine errors that AW made with regular verb forms, five were no-change errors (*die* → "die"), three were -s addition errors (*happen* → "happens"), and one was a stem-change error (*link* → "lunk").

The irregular past tenses and their stems vary in the degree in which they differ from one another: in some cases the difference only involves a single vowel (as in *dig–dug*) or a single consonant (as in *lend–lent*), both a vowel and a consonant (as in *bring–brought*, *seek–sought*), and there are also cases in which their forms are identical (as in *hurt–hurt*, *shut–shut*). Patterson et al. (2001) examined whether this variability affected the probability of producing a correct response in their patients with semantic dementia. The highest correct rate was found with those verbs that differ only by a consonant (76%), whereas the lowest correct rate appeared with those verbs that undergo no changes (33%; McNemar $P < 0.001$). For irregular past tenses, the consonant change always results in verbs that end with /t/ or /d/ (*make–made*, *creep–crept*, etc.), a fact that led Patterson et al. (2001) to speculate that consonant-change irregular verbs represent an intermediate case between regular verbs and irregular verbs with less predictable changes. This may explain why patients with spared processing of regularly inflected verbs perform relatively better with consonant-change irregular verbs. To verify whether the same pattern holds for AW, the irregular verbs selected for the past tense generation tasks were divided into four groups, depending on whether a vowel, a consonant, or both or neither changed between the present and past tense. The results of AW contrast with those reported by Patterson et al. (2001): AW's highest correct rate is found with no-change irregular verbs and one of her lowest correct rates emerged with consonant-change irregular verbs (see Table 6). Although the results of both studies are not based on a large number of observations and should therefore be interpreted cautiously, the difference in the findings leads one to suspect that individual patients may be sensitive to different types of changes and adopt different kinds of "default strategies". AW might have used a "no-change strategy", and would consequently tend to respond by repeating the stem; this would explain why she was particularly accurate with no-change irregular verbs and why no-change errors were relatively frequent. Conversely, the patients of Patterson et al. (2001) might have paid more attention to cases involving consonant change.

A regression analysis revealed that while lemma (stem) frequency was a reliable predictor ($P < 0.05$) of AW's responses with irregular past tenses and past participles, the frequency of the irregularly inflected forms (their surface frequency) was not. The finding of a (stem) frequency effect is a result anticipated by both the dual-mechanism account and

Table 6
AW's *N* (%) correct responses with various types of irregularly inflected verbs

Type of change	Examples	Generation task					
		Past tense				Past participle	
		With sentences		Without sentences			
		N^a	% correct	*N*	% correct	N^a	% correct
Vowel change	*eat* → "ate"	130	71	65	70	74	72
Consonant change	*make* → "made"	14	71	7	43	12	50
Vowel + consonant change	*lose* → "lost"	30	63	16	69	82[b]	50
No change	*hit* → "hit"	26	80	13	77	26	77

[a] Data combined from two administrations of the test.
[b] Past participles with final -(e)n (e.g. *broken*) are included in this group.

the account proposed by Joanisse and Seidenberg (1999) (see Patterson et al., 2001; Pinker, 1991 for a discussion of this issue); the finding is also consistent with AW's results in the picture naming task, where a (lemma) frequency effect was also obtained. There are various accounts to which one may appeal to explain why surface frequency is not a valid predictor. One possibility is that frequency estimates are less reliable for surface frequency than they are for stem frequency. Gernsbacher (1984) has shown that written frequency counts like those used in the present study tend to be particularly inaccurate in the low frequency range. Of the irregularly inflected verbs used in our tasks, only 6% have low frequency stems (less than 10 counts per million), whereas 36% of their past tenses and past participles fall within this range. The lack of a surface frequency effect could then reflect the large proportion of irregular forms with low surface frequency. An alternative explanation can be found in models which assume that (a) different lexical representations exist for a verb's stem and for its irregular form and (b) only access to verb stem is sensitive to frequency. Models of this sort would only predict a stem frequency effect. Further research is needed to clarify the reasons why surface frequency does not affect verb production.

Imageability, the ease with which people can form a sensorial image of the concept expressed by a word, is a variable that affects the performance of patients with semantic damage, as there have been reports of patients who were better with high vs. low imageability words (Warrington, 1975). Whether imageability influenced AW's performance with irregularly inflected verbs was controlled. Ten college students rated the verb stems for imageability on a 7-point scale, where 1 corresponded to very low imageability and 7 to very high imageability. The irregularly inflected verbs used in each task administered to AW were divided into two groups; one group was composed of low imageability verbs (3.5<), the other of high imageability verbs (>3.5). Table 7 shows the distribution of AW's correct responses as a function of verb imageability. The results are not clear-cut, as can be seen in Table 7, which also reports the statistics for the comparisons between high and low imageability verbs. Correct response rate is higher for high as opposed to low imageability verbs only in two of the five tests. If this result suggests a very weak effect of

Table 7
AW's *N* correct responses with irregularly inflected verbs as a function of verb imageability

Task	*N* (%) correct/imageability		High vs. low imageability (χ^2s)
	Low	High	
Past tense, with sentences			
First administration	20/30 (66)	60/70 (86)	4.76 ($P < 0.05$)
Second administration	18/30 (60)	45/70 (64)	0.16 (NS)
Past tense, without sentences	22/32 (69)	46/63 (73)	0.18 (NS)
Past participle, without sentences			
First administration	16/32 (50)	41/65 (63)	1.51 (NS)
Second administration	16/32 (50)	46/65 (71)	4.00 ($P < 0.05$)

imageability, it also lends little support to the hypothesis that a semantic impairment is at the root of AW's deficit with irregularly inflected verbs: were a semantic deficit present, a robust effect of imageability should have been observed.

4.5. Generation task: novel verbs

In this task, AW generated the past tense of the novel verbs read aloud by the experimenter. AW was presented with 70 monosyllabic novel verbs whose pronunciations conform to the phonotactic rules of English. The novel verbs were of two types: (a) *similar*, obtained by changing the onset of existing irregular past tenses (as in *crive–drive*, *frink–drink*; $N = 18$; 16 were from van der Lely & Ullman, 2001); and (b) *dissimilar*, intended to sound different from existing irregular past tenses (e.g. *weeg*, *rast*; $N = 52$; 20 were from Ullman et al., 1997). Responses were first scored according to whether AW added the suffix -ed. This was observed in 61/70 (87%) responses. Fourteen of these responses were like *kelt* → "kilted" or *slock* → "socked", where the (pseudo) stem was incorrectly reproduced. The latter errors are likely to reflect problems in repeating the stem, as suggested by the data of a control test in which AW only repeated the stem and in which errors were also observed (64/70, 91% correct). AW appended the -ed suffix more frequently with dissimilar than similar novel verbs (49/52, 94% vs. 12/18, 66%; χ^2s, $P < 0.01$).[8] If we exclude AW's occasional problems reproducing the stem, she responded like normal controls, who also produced +ed forms more commonly with dissimilar (93%) than with similar novel verbs (51%) (similar results with normal controls have been reported by Thomas et al., 2001).

4.6. Generation task: noun plural

In the last generation task, AW produced noun plurals which were either regularly inflected (*dimes*, *lambs*, *gloves*) or irregularly inflected (*children*, *feet*, *deer*). The list of irregular plurals used in the task is necessarily short ($N = 21$), since there are few such nouns in English and some are not likely to be familiar to AW (*bacterium–bacteria*, *cactus–cacti*). Each irregular plural was paired with a noun with a regular plural and with a comparable lemma frequency (mean: irregularly inflected nouns 214, regularly inflected nouns 68; $t(20) = 1.3$, $P = 0.19$). The experimenter read aloud the singular nouns and AW produced their plural. AW correctly produced 9/21 (43%) irregular plurals and 20/21 (95%) regular plurals ($\chi^2 = 13.4$, $P < 0.001$). All her errors with irregularly inflected nouns consisted of regularizations, for example "childs", "deers", and "shelfs". Controls were 100% correct with both types of plurals. Although limited in number, these errors reveal that AW's problems with irregular inflections extend to nouns.

[8] The responses to novel verbs not containing the -ed suffix were: slud → "slud", weeg → "wog", cleed → "cleed", rast → "rast", brop → "brop", strink → "drank", strise → "stride", frink → "frink", and shrim → "shrum".

4.7. Summary

The tasks presented in this section required AW to generate regularly and irregularly inflected verbs and nouns, and the main results obtained in these tasks are the following.

(a) AW shows a deficit in producing irregular inflections. For regular forms, AW's performance is remarkably preserved and comparable to that of normal controls (see Table 4). The clear-cut dissociation between regular and irregular forms appears with different inflections – past tenses, past participles, and plurals.

(b) Novel verbs tend to be normally inflected by AW who responds like normal controls in generating the past tense of novel verbs. This finding further confirms the intactness of mechanisms responsible for normal inflections in AW.

(c) Stem frequency affects AW's responses, which tend to be more accurate for verbs with high vs. low stem frequency.

(d) AW's errors with irregularly inflected verbs were mainly regularizations (*hold* → "holded", *choose* → "choosed") and attempts to replicate the patterns observed with real verbs (replication of the present tense, as in *hold* → "hold" or consonant/vowel changes, as in *sing* → "sung").

(e) The fact that AW is correct with regularly inflected verbs and nouns suggests that she can access information about syntactic features such as verb aspect and noun number, which are assumed to be stored at the lexical level. The source of AW's word production deficit seems to be one of retrieving the word phonology from the lexicon.

The fact that results (a)–(e) appear in a patient who has problems in retrieving word phonology but spared semantic processing has several implications for current models of language processing that will be addressed in Section 5.

5. General discussion

AW is a patient with acquired word-finding difficulties caused by a left-temporal lesion. Detailed analyses indicate that AW's naming impairment is due to a problem of retrieving word phonology. When the patient failed to produce a word, very rarely could she retrieve fragments of the sound of the recalcitrant word; by contrast, AW seemed able to access precise semantic descriptions of objects as evidenced by her excellent performance even in demanding semantic tasks with nouns and verbs. Of particular interest for language theories is AW's performance with inflected verbs. AW showed a stark dissociation in tasks in which she was presented with verb stems and generated their past tenses or their past participles: while she performed extremely accurately with regular inflections, she was markedly impaired with irregular inflections. It can be ruled out that the intact performance with regularly inflected verbs arose because AW adopted an "add -ed" strategy (i.e. append the suffix -ed at the end of the verb stem). If this were the case, with irregularly inflected verbs AW would have produced a large number of errors like *sinked* or *hided* (regularizations) which instead accounted for only 37% of her errors with irregular verb forms. AW encountered similar problems in producing the irregular plural of nouns like *children*, *deer*, and *shelf*. In short, the data obtained from AW reveal that in conditions of impaired retrieval of word phonology but intact access to word meaning, the processing of regular inflections can be normal, whereas the processing of irregular inflections can be damaged.

There are similarities and differences between the results of AW and those of patients with semantic deficits associated with semantic dementia (Patterson et al., 2001) or with temporal damage caused by encephalitis (Tyler et al., 2002). As with AW, these patients show selective problems in generating the irregular past tense, especially with low frequency verbs. But in contrast to AW, these patients show a semantic deficit. For example, while AW was able to choose a verb's synonym (*walk–stroll*), patients with semantic dementia were impaired in this task. How can we reconcile these differences? A possible solution is to propose that the deficit for irregular verbs observed in patients with impaired semantic processing is not caused by a semantic deficit but rather by a lexical deficit similar to the one described in AW. This hypothesis gains plausibility if we consider that anomia has been included as one of the deficits observed in semantic dementia (Hodges, Patterson, Oxbury, & Funnell, 1992; Snowden, Goulding, & Neary, 1989). Unfortunately, Patterson et al. (2001) do not report data that allow us to determine whether access to word phonology is spared in their patients, and therefore it is not possible to establish whether the results from semantic dementia are at odds with those documented in AW. Similar considerations hold for the four patients with semantic impairment tested by Tyler et al. (2002), with the exception of their patient JBR. This patient was initially reported by Warrington and Shallice (1984) who noted "occasional word-finding difficulty" and the tendency "to use circumlocutory expressions" (p. 832), which are signs that lead one to suspect problems of word phonology retrieval.

The idea that a semantic deficit is not the source of the problems with irregular verbs shown by patients with semantic deficit is not new: Marslen-Wilson and Tyler (1998) appealed to the same idea to explain why their patients did not show priming with semantically related pairs (*white–black*) as well as with pairs formed by irregular verbs (*gave–give*). Noticeably, these authors also cited data that cast doubts on the hypothesis that semantic processes are critical for the processing of irregular past tense verbs. For example, in the delayed repetition paradigm, while facilitation was observed only at short intervals with pairs like *white–black*, facilitation lasted longer with pairs like *gave–give*. Moreover, in ERP experiments, different profiles of activation were recorded between prime–target pairs like *black–white* and pairs like *gave–give*. If semantic processing was indeed critical for irregular verbs, priming effects with these verbs should parallel those obtained with semantically related words.

The hypothesis that semantic deficits are not the source of the impairment for irregular past tense also obtains a degree of neuroanatomical plausibility from AW's data. All patients with irregular past tense impairment documented thus far present with left temporal lesions, and AW is no exception. Tyler et al. (2002) were able to show that the deficits for irregular past tenses and semantic processing observed in their four patients were consistently associated with extensive damage to the left inferior temporal gyrus. This area appears to be spared in AW – her lesion affected the medial and superior temporal regions. Data from functional neuroimaging studies link left inferior temporal areas to semantic processing (Vanderburghe, Price, Wise, Josephs, & Frackowiak, 1996). Consistent with these data, one might speculate that it is because her semantic areas are (relatively) spared that her semantic processing is intact. If this speculation is correct, it means that semantic and lexical processes take place in distinct temporal areas (inferior vs. medial-superior). Of course, speculations based on the neuroimaging records of a single brain-damaged patient are necessarily limited and speculative, and future research will prove the validity of these conclusions.

Joanisse and Seidenberg (1999) designed a connectionist model that simulates the stem → past tense generation test. The principle feature of this connectionist model, as we have seen in Section 1, is that identical mechanisms underlie the processing of regular and irregular past tenses, though semantic and phonological units are involved to different degrees in the processing of each type of verb. In computer simulations, following lesions of the phonological units, the rate of correct responses in the generation task decreases for regular, irregular, and novel past tenses, though the most severe effects are seen with novel forms. This pattern was not replicated with AW who, as a consequence of impaired access to phonology, fails exclusively with irregularly inflected verbs. In computer simulations, severe (though not exclusive) deficits for irregular past tenses arise following semantic damage. Again, AW's data are inconsistent with the simulation data: all tests indicate that AW's semantic processing is intact, and yet her damage is circumscribed to irregularly inflected verbs.

AW's impairment is problematic for the Joanisse and Seidenberg's (1999) connectionist model not only because it shows that a deficit for irregular inflections can be associated with impaired access to phonology, but also because of its selectivity. In computer simulations of the model, lesions to semantic or phonological units do not cause selective deficits, rather they affect (to a different degree) all classes of verb inflections (regular, irregular, and novel); by contrast, AW performs like normal controls with regular and novel inflections. But there is mounting evidence that is incompatible with the qualitative aspects of the model. Among the patients with semantic impairments reported by Patterson et al. (2001) and by Tyler et al. (2002), we find individuals who performed normally with regular and novel past tenses in the elicitation tasks, but who are impaired with irregular past tenses. If we turn to patients with deficits for regular forms, we find results that do not fit other qualitative aspects of Joanisse and Seidenberg's model. The model predicts that deficits for regular past tenses would appear along with deficits for irregular past tenses of equal severity. However, there is one patient (FCL; Ullman et al., in press) who performs significantly more poorly at producing regular than irregular past tenses (20% vs. 69%, respectively).

It remains to be seen how the Joanisse and Seidenberg (1999) model would simulate past tense processing in tasks like reading and auditory judgment, for which data are available from brain-damaged patients. The pattern that has emerged in these tasks diverges in part from the pattern that Joanisse and Seidenberg (1999) obtained in their simulations of the past tense generation task. In reading, some patients had more severe problems for regular than irregular past tenses (see Ullman et al., 1997, in press for a review of these cases), and in the auditory judgment task, patients with no apparent phonological deficit were impaired with regular past tenses (Tyler, Randall, & Marslen-Wilson, 2002). Finding that the simulations of these tasks parallel the simulations of the elicitation task would be highly problematic for the model.

The potential importance of the Joanisse and Seidenberg's (1999) computer simulations, and what makes them differ from previous connectionist models, is their ability to simulate selective deficits for regular or irregular past tenses. The data of AW, but also those from other patients, question whether the model implemented by Joanisse and Seidenberg (1999) is fully capable of successfully replicating the neuropsychological data. We should not forget that computer simulations rely on the specification of a number of parameters and it is not until a systematic exploration of the whole range of parameters has been accomplished that the strengths of the model can be fully assessed. We should also acknowledge that the Joanisse and Seidenberg's (1999) computer implementation is limited in many respects – for example, each verb is represented by a unique semantic node, a localist representation that cannot capture semantic similarity. A question that remains to be tested empirically is whether, perhaps in a connectionist model with an enriched structure, it is possible to identify a set of parameters that successfully replicate the selective dissociations documented in neuropsychology.

The data of AW are fully compatible with the dual-mechanism account. According to this account, for regular words there are mechanisms that operate on the basis of morphological rules and are responsible for linking a stem (*walk*) with its affixes (*-ed*). Irregular forms are individually stored in the lexicon, and lexical access is required for successfully producing past tense forms like *though*, *made* or *went*. Within the dual-mechanism account, deficits of lexical access are then expected to cause impairment that selectively affects the generation of irregular past tenses. AW's deficit is in line with this prediction. Rule-based mechanisms are supposedly spared in AW and this explains her virtually intact performance not only with regular past tenses but also with novel past tenses. Because rule-based mechanisms are typically recruited with novel verbs, AW could rely on these mechanisms in order to generate the past tense forms of novel verbs. According to the perspective of the dual-mechanism account, it is far from surprising to observe dissociation as clear-cut as in AW, in which the processing of regular inflections remains virtually intact. Because of their different nature, the processing of regular and irregular inflected forms may take place in anatomically segregated brain structures, which can be selectively damaged and give rise to selective deficits such as the one seen in AW as well as in other patients.

The dual-mechanism account is a general hypothesis that can be implemented in various ways. The declarative/procedural model is a specific implementation that Ullman (2001) has recently proposed in the context of a broader theory of language and memory. The lexicon is assumed to be part of the declarative system, which is also devoted to the processing of knowledge about facts (semantic knowledge) and events (episodic knowledge). Aspects of the language that involve rule-based mechanisms (grammar and morphology) are viewed as part of a procedural system which is implicated in learning and processing skills that require sequencing of mental representations or motor activities. Within this account, the processing of regular and irregular past tenses is under the domain of the procedural and the declarative system, respectively. The latter claim is supported by an impressive array of neuropsychological evidence. Neuropathologies known to affect episodic and semantic memory (e.g. Alzheimer's dementia) are associated with deficits that affect the processing of irregular past tenses more severely. By contrast, problems in producing regularly inflected past tenses for novel verbs have been observed in neurodegenerative impairments such as Parkinson's disease and Huntington's disease, which affect the learning and execution of sequential components in various activities. Patients like AW offer a unique opportunity to test the declarative/procedural model. Given the link made by the model between the processing of irregular past tense verbs and episodic memory, the model would not anticipate that patients with a selective impairment for irregular past tense verbs show no deficits in the consolidation and retrieval of episodic memories.

There are other implications for understanding how regular and irregular inflections are processed that follow from AW's data. The first implication concerns the errors she produced with irregular verb forms and the fact that only a fraction of her errors consist of regularizations ("*falled*", "*runned*"). Patterson et al. (2001) and Ullman et al. (1997) also observed a variety of errors in their patients with deficits for irregular verbs. What such an error pattern reveals is that in a number of cases patients know that a verb takes an irregular form and hence do not append the suffix -ed to its stem. But because phonology remains inaccessible, they can only guess the verb form; so, for example, they change a vowel or a consonant to produce verbs that resemble existing irregular verb forms. In other words, it seems that the regular/irregular status of the verb is information that is stored separately from the form of the irregular verb. In anomia, this information can be accessible, although the form of the irregular verb remains elusive. Perhaps the function of the information about the regular/irregular status of the verb is to block the suffixation process and to trigger the retrieval of the irregular form from stored phonology (for a similar proposal see Pinker, 1991).

A second implication relates to AW's remarkable ability to generate regularly inflected verbs. In English, the rules of past tense formation are quite complex, since the realization of the -ed suffix varies as a function of the phonology of the stem. If the stem ends with a voiced consonant (as in *bare*) the suffix is /d/, if the final consonant is unvoiced (as in *bake*) the suffix is /t/, and if the final consonant is an alveolar stop /t/ or /d/ (as in *bait*) the suffix comprises an unstressed vowel (schwa) and /d/. AW produced a large number of verbs in each of these classes and her responses were almost always correct.[9] If the characterization of AW's impairment as a problem of retrieving the lexical phonology is correct, AW's intact processing of regular verb inflections implies that the lexicon does not specify how the -ed suffix is realized in individual verbs. Instead, it seems that mechanisms that adjust the morpheme -ed to the phonological context of the stem are responsible for the correct realization of the past tense suffix. These mechanisms necessarily operate at a level of representation where the voiced–voiceless status of phonemes is specified.

Finally there is the observation that AW's problems with irregular inflections extend to nouns and so she produced plural forms like "childs", "deers" and "shelfes". Anecdotal though these errors may be, the co-occurrence of errors for both verbs and nouns is an important finding because it suggests that even if the exceptional forms of these grammatical categories differ on a variety of dimensions – most notably, number and frequency – they are similarly processed.

In conclusion, I have documented that impaired semantics is not associated with a deficit for producing irregular inflections. This finding is at odds with the view that semantics is critical for encoding irregular past tense forms. Instead, AW's data are in

[9] Overall AW produced 642 regular verbs (489 in the tests presented in Part 2, and 153 in a test in which AW was presented only with the present tense of regular verbs). In these verbs, the -ed suffix is realized as follows: /d/ 55%, /t/ 23%, schwa + /d/ 22%.

line with the view that language is "encapsulated" from semantics and that idiosyncratic linguistic forms are specified solely within the language system. The latter view finds further support from the fact that AW's highly selective deficit for irregular inflections arises as a consequence of impaired lexical access. AW's data are also consistent with a brain organization of language that assumes that mechanisms specifically devoted to morphological (rule-based) processing are anatomically distinct from mechanisms devoted to irregular forms. Of course this view predicts there should be patients with selective impairments for regular past tenses. The increasing number of patients with this form of deficit represents another piece of evidence in support of the proposal that regular and irregular inflections are differently represented in the brain.

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