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PLATFORM SESSION 1: MORPHOLOGY

Brain Activation during Encoding of Inflected Words

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In languages like Finnish which have a very rich morphology, it is not surprising that particularly inflected forms appear to undergo morpheme-based access (e.g., Laine et al., 1999). As this process is fast and automatic, one would expect that dedicated left-hemispheric neural systems subserve such functions. Earlier studies with brain-damaged patients and normals have indicated that the left anterior language zones are particularly important for the output of (regular) morphology (Miceli, 1999; Jaeger et al., 1996; Ullman et al., 1997). It is an open question whether the left anterior dominance observed in morphological output extends to input as well, i.e., could there be some central mechanisms for morphological processing which are shared by both output and input? A recent PET study revealed increased activation in Broca's area during semantic plausibility judgments with syntactically more vs less complex sentences (Stromswold et al., 1996) but the nature of the task prevented the pinpointing of the exact mechanisms of this effect. In the present study, we focused on a simpler task in which normal subjects tried to memorize auditorily presented word lists consisting of either case-inflected or monomorphemic nouns while regional brain activation was measured by PET (oxygen-15 water). In this task, regional activation differences between the two conditions should reflect the effects of lexical-morphological processing.

Materials. Twelve 50-word lists were compiled. Six lists consisted of monomorphemic (base form) nouns (e.g., KOMPASSI, ''compass'') and the other 6 included case-inflected nouns (e.g., TUOLI+STA, ''chair + from''). The items were matched by lemma frequency (mean 10.4 per million for inflected, 10.9 for monomorphemic) and by average length in phonemes (mean 7.0 for both types). The 12 lists were presented via a tape player in a pseudorandom order.

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Six right-handed healthy male volunteers (ages 23–27) served as subjects. They were instructed to memorize the auditorily presented words as well as they were able to. Proper attention was verified by a short recognition memory test following each list. The actual task was preceded by a practice trial.

PET procedure. Each subject underwent 12 PET scans within a single session. Scans were obtained by a GE Advance scanner providing 35 transverse sections through the brain spaced 4.25 mm apart. On each trial, task performance started 15 s before the intravenous bolus administration of 200 MBq [^{15}O]water. The data were framed into a single frame of 90 s. Image analysis was performed using the Statistical Parametric Mapping (SPM96) software. Each reconstructed [^{15}O]water scan was realigned and normalized using a PET template. Differences in global activity within and between subjects were removed by the analysis of covariance. Voxels were identified as significantly activated if they passed the height threshold of $Z = 3.09$ ($p < .001$) and belonged to a cluster of at least 130 activated voxels ($p < .05$, corrected for multiple comparisons).

Results. The average recognition memory performance (max 10) for case-inflected and monomorphemic words was 8.1 (SD 1.0) and 8.7 (SD 1.0), respectively [$F(1, 5) = 3.83$, $p =$ n.s.], indicating proper attention to the task.

Significant rCBF increases comparing encoding of case-inflected vs monomorphemic nouns were observed in Brodmann areas 44/45 on the left, corresponding closely to Broca's area (Fig. 5). Exploration of the data with a more lenient threshold ($Z = 2.33$, $p < .01$, uncorrected for multiple comparisons; data not shown) showed rCBF increases in additional predominantly left-hemispheric regions as well: the homologous right frontal area 44/45, left Brodmann area 22 corresponding to Wernicke's area, Brodmann area 6 on the left (corresponding to premotor and supplementary motor area), right postcentral gyrus, and left cerebellum.

Conclusions. Our results showed activation increases mainly in Broca's area during encoding of case-inflected words, suggesting that this area and adjacent regions are important not only during retrieval but also during access to morphologically complex regular words. Even though production vs comprehension impairments of grammatical morphology can dissociate (Miceli, 1999), it is nevertheless possible that some components of morphological processing are shared by both production and comprehension. Our results suggest that lexical–morphological analysis may include shared processing components and that they are subserved by the left anterior language regions.

Earlier PET studies have shown activation of Broca's area also during verbal memory tasks (Cabeza & Nyberg, 1997). As we employed a memory paradigm, it is quite possible that our activation results reflect both primary and secondary effects of morphological processing: in addition to morpho-

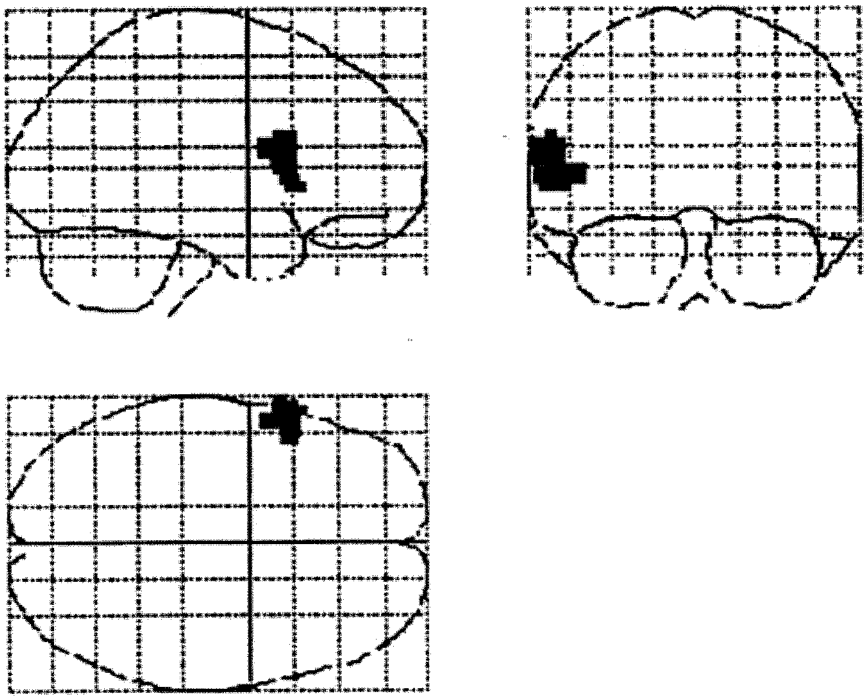

FIGURE 5

logical decomposition needed for the inflected words, there is a greater memory load for the inflected than for the monomorphemic targets.

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Morphological Impairment in Acquired Dyslexia: Distinguishing Morphological, Semantic, and Orthographic Information

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Some theories of language processing have postulated that there is a level of representation or processing at which morphemes are treated differently from whole words (e.g., Marslen-Wilson, Tyler, Waksler, & Older, 1994). Support for these theories has been derived, in part, from patients with acquired dyslexia who exhibit errors such as reading initiate as initiative or bakery as bake.

Acquired dyslexics who make this type of error generally also make semantic errors (e.g., lotion → cream) and visual errors (e.g., brothel → brother). In the analysis of error types, while visual errors can be distinguished easily from semantic errors, morphological errors are readily confused with both semantic errors and visual errors (i.e., reading initiate as initiative could be a semantic, visual, or morphological error). Here, we consider whether ''morphological'' impairment in acquired dyslexia does indeed reflect damage to a component of the reading system that is specifically morphological or whether it can be explained in terms of damage to visual and/or semantic components.

Patient. DE has been described extensively in the literature (e.g., Patterson & Marcel, 1977) as a classic deep dyslexic patient. He suffered a CVA in 1970 (age 16); an MRI taken in 1996 revealed a large LH lesion affecting most of the temporal lobe and middle and posterior parts of the frontal lobe. DE was age 44 at the time of testing.

Experiment 1. Funnell (1987) has argued that morphological errors in acquired dyslexia may be a type of error which arises when a target word cannot be read aloud due to its level of imageability and/or frequency. Letters are subtracted, added, or substituted from the target word to form a word higher in frequency and/or imageability. By this account, these apparently morphological errors do not reflect a deficit in morphological processing or representation per se, but rather a general impairment by which frequency and imageability are maximized, generally by extracting words embedded in the target stimulus (a structure characteristic of most morphologically complex words).

TABLE 12
Results of Experiment 1

	% Correct	% Root errors (of errors)	% Root + wrong affix (of errors)
Suffixed (N = 52) (e.g., smoothly)	40.38%	80.6%	62.5%
Pseudosuffixed (N = 62) (e.g., cower)	43.50%	48.57%	22.86%
Embedded (N = 61) (e.g., cornea)	52.4%	72.4%	24.13%

To test this account, we designed three lists of stimuli for reading aloud—suffixed words (e.g., smoothly), pseudosuffixed words (e.g., cower), and embedded words (e.g., cornea). Each target stimulus contained an embedded ''root'' word (e.g., smooth, cow, and corn). Lists were matched on word frequency, word imageability, root frequency, and root imageability. One hundred twenty-five morphologically simple, imageable, and frequent filler items which did not contain embedded words were included. If Funnell's (1987) account is correct, then the incidence of errors containing the root should be independent of morphological condition, as should the percentage of items read correctly.

The results (Table 12) showed no difference in the percentages of words read aloud correctly over the three conditions, $\chi^2(2) = 1.83$, n.s. Thus, when the root and whole word are controlled for imageability and frequency, morphologically complex items are no more difficult for DE to read aloud than morphologically simple items, a result inconsistent with previous claims that he has particular difficulty with morphologically complex words.

Similarly, the incidence of errors containing the embedded root word did not vary significantly by condition, $\chi^2(2) = 5.34$, $p = .07$. Rather, the incidence of root errors was predicted by the relationship between the imageability and the frequency of each target and its embedded root across all conditions. Items which resulted in root errors contained embedded words which were high in frequency and imageability relative to the target (e.g., cower, armada), compared with items which did not produce root errors [frequency $F(1, 173) = 10.40$, $p < .01$; imageability $F(1, 173) = 4.17$, $p < .05$]. Thus, Funnell's (1987) hypothesis is supported here. The relationship between target and root on factors such as imageability and frequency predicts the incidence of root errors and correct responses, irrespective of the morphological complexity of the stimulus.

Subtler analyses, however, suggest that DE's performance may be indicative of morphological impairment. When errors were committed they were generally of a different type for morphologically complex items than for the other item types. Incorrect responses for morphologically complex items consisted of affixes and, in particular, the root word plus an inappropriate suffix (e.g., option → opting) more often than was the case for the other item types, $\chi^2(2) = 15.79$, $p < .01$.

Experiment 2. While the results of Experiment 1 provided some support for Funnell's claims, they also indicated that morphologically complex items are treated differently from simple items. In particular, incorrect responses to morphologically complex words tended to contain affixes more often than was the case for the other item types, indicating perhaps that DE's impaired reading performance is constrained by a level of analysis that is morphological.

There is another possible explanation for errors such as option → opting, however. Perhaps these errors are a reflection of the semantic impairment characteristic of deep dyslexia; these errors could occur frequently for morphologically complex words simply because of the availability of a number of close semantic alternatives to the target which also share orthographic information. In Experiment 2, we pursue this possibility in a speeded cross-modal verification task designed to assess whether DE finds morphological relatives (e.g., darkly–darkness) more difficult to discriminate than pairs of words which are semantically and orthographically related to the same degree as the morphological pairs (e.g., scrape–scratch).

Four lists of stimuli were created in which morphological, semantic, and orthographic factors were varied.

Set 1: morphologically, semantically, and orthographically related pairs (e.g., darkly–darkness; baker–bakery).

Set 2: semantically and orthographically related pairs (e.g., scrape–scratch; plunge–plummet).

Set 3: semantically related pairs (e.g., chore–duty, compost–manure).

Set 4: orthographically related pairs (e.g., typhoid–typhoon, merger–mercy).

All sets were matched on frequency and imageability, Sets 1–3 were matched on semantic relatedness, and Sets 1, 2, and 4 were matched on orthographic relatedness. DE was given one member of each item pair auditorily and asked to decide quickly whether the other member, presented visually, matched what he had heard. If DE's deficit involves specific damage to morphology, then he should show slower reaction times and greater error rates for judgments regarding words in Set 1 than for judgments regarding the other target items. Preliminary results suggest that this is indeed the case.

Together, these experiments suggest that morphological impairment in acquired dyslexia cannot be subsumed under a more general visual or semantic impairment, though the incidence of morphological errors in acquired dyslexia has probably been overestimated due to poor control over factors such as imageability and frequency. We discuss these results within the framework of the theory of lexical representation proposed by Marslen-Wilson et al. (1994).

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Broca's Aphasia and German Plural Formation

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The system of German plural inflection has been notorious for the problems it poses to theoretical analysis: Plural nouns are marked by the affixes *-e, -er, -(e)n,* or *-s* or remain unmarked. In addition, unmarked plurals and plurals on *-er* and *-e* can show umlauting of the stem vowel. This system is, to varying degrees, idiosyncratic and has been subject to major debates centering upon the question which of these plural forms are affix based and which are stored as idiosyncratic forms (Marcus et al., 1992). Recently, the Dual-Mechanism Model of inflection (e.g., Pinker & Prince, 1988), which proposes two different cognitive processes for regular and irregular inflection, has been applied to the German plural system. Based on the different behavior of *-s* plurals in psycholinguistic experiments, Clahsen et al. (1997) have argued that *-s* is the only regular plural affix in German (see also Marcus et al., 1995). In this account, all other noun plurals are said to be irregular and stored as full forms in the mental lexicon. In this paper, we argue that a closer investigation of aphasics' errors with German noun plurals can shed more light on the system of plural formation.

We elicited noun plurals from nine German Broca's aphasics with agrammatic speech production. All subjects had suffered from a left-hemispheric stroke at least 3 years before our investigation and had a stable aphasic disorder.

Subjects were instructed to transform a given singular noun into the respective plural form (cf. (1)). The noun phrases were presented on cards placed before the subjects and read out aloud together with them.

1 Kind, 2 ____ (''1 child, 2 ____'') (1)

We elicited 20 noun plurals for each of the plural markers *-s, -e,* and *-er* and two types of *-n: -n* plurals for feminine nouns ending in -* (hence *-n* ^{fem})

and *-n* plurals for masc./neuter nouns not ending in -* (hence $\text{-}n^{masc}$). In total, we elicited 876 analyzable noun plurals.

The analysis of error-patterns in the elicited data led to the following results. All nine subjects had significant differences between the error rates for *-s* plurals and the other plural forms (χ^2, $p < .05$ for each subject). Eight subjects showed clear deficits for *-s* plurals, whereas the other plural forms were significantly better retained. Only one subject showed the reverse pattern: virtually no errors for *-s* plurals, but significantly higher error rates for the other plural forms. Moreover, a comparison of the data for two of our subjects revealed a double dissociation in the error distribution between *-s* and the other plural markers: While subject M.B. had problems only with *-s* plurals and not with any of the other markers, subject A.H. showed the reverse pattern, i.e., no problems with *-s* but with the other markers. In sum, our data reveal a clear dissociation between *-s* and the other plural forms: *-s* can be selectively disturbed or retained in agrammatism. The data, thus, provide evidence for a qualitative distinction between *-s* and the other plural markers.

However, a closer look at the plural markers other than *-s* revealed that they do not behave as uniformly as predicted by the Dual-Mechanism Model on German plurals (Marcus et al., 1995; Clahsen et al., 1997). According to this account, noun plurals on *-e*, *-er*, and *-n* are stored as fully inflected forms in the mental lexicon. Crucial for this proposal is the role of *-n* plurals. The plural marker *-n* is completely predictable for feminine nouns which end in -* in the singular (= here $\text{-}n^{fem}$). In contrast to the Dual-Mechanism Model, it has therefore been suggested that the *-n* marking on these nouns is based on a process of regular affixation (e.g., Wiese 1996). On the other hand, the *-n* marking is not predictable for masc./neuter nouns that do not end in -* in the singular (= here $\text{-}n^{masc}$). Accordingly, these forms are generally assumed to be stored (e.g., Wiese 1996).

If the two types of *-n* plurals were stored, as predicted by the Dual-Mechanism Model, no different error rates between the $\text{-}n^{masc}$ and the $\text{-}n^{fem}$ plurals should occur. However, for four of our subjects plurals on $\text{-}n^{masc}$ were significantly more impaired than plurals on $\text{-}n^{fem}$ (χ^2, $p < .05$ each). Moreover, the data of two of these subjects show that $\text{-}n^{masc}$ plurals can be impaired whereas $\text{-}n^{fem}$ plurals are not affected at all. Thus, the data indicate that the two types of *-n*-marked forms can be affected differently by the agrammatic deficit.

The frequency distribution of errors provides further evidence against a unitary analysis for the two types of *-n* plurals. If both—plurals on $\text{-}n^{masc}$ and $\text{-}n^{fem}$—were stored, frequency effects caused by the access of stored lexical items should be observable for both markings. Indeed, the data revealed a frequency effect for $\text{-}n^{masc}$ plurals: errors occur more often with infrequent forms than with frequent ones (Wilcoxon, $p = 0.068$). However, there is no frequency effect for $\text{-}n^{fem}$ forms ($p = .58$). Thus, the frequency distribution of error rates indicates that -*n*^{masc} plurals are stored irregular forms, whereas -*n*^{fem} plurals are built by affixation.

In sum, our data call for a modification of the Dual-Mechanism account on German plural formation. Our results confirm the dissociation between the default marker -*s* and the other plural markers. However, the data on -*n* plurals suggest that plural markers other than -*s* cannot uniformly be treated as irregular stored forms. In particular, we propose that the -*n*^{fem} plurals are built by regular affixation.

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Quantifying Dissociations in Aphasia

Mark Appelbaum and Elizabeth Bates

Double dissociations have played a crucial role in neuropsychology and aphasia, often regarded as the ‘‘necessary and sufficient condition’’ to test any hypothesis concerning the association between a functional loss and a lesion in a specific location in the brain (Bouillaud, 1825; Luzzati & Whitaker, 1999; Teuber, 1955). Increasingly sophisticated versions of this concept have developed over years (Bates et al., 1991a,b; Kinsbourne, 1971; Marin, Saffran, & Schwartz, 1976; Shallice, 1988; Weiskrantz, 1968), but the classical formulation can be described as follows: Two groups or two single cases (P1 and P2) show differential impairments in tasks A and B, such that P1 is impaired in task A but spared in task B while P2 is impaired in task B but spared in task A. Under these conditions, it must be concluded that the pattern of impairment ‘‘may be drawn by two independent functions, F1 and F2 involved in tasks A and B’’ (Vallar, 1999). This methodological tool has been used extensively in both group and single-case studies to ‘‘elucidate the multicomponential architecture of mental functions and their neural basis’’ (Vallar, 1999). However, such proposed dissociations are often based upon subjective estimates of a ‘‘high performance’’ in one task and a ‘‘low performance’’ in another, without concern about the probability that such an outcome could have occurred by chance if patients were drawn randomly from the normal population or from some reference population (e.g., large unselected samples of brain-injured patients). When inferential statistics are applied, researchers sometimes make unwarranted assumptions about independence and the equivalence of variances and means between the two measures in question, leading to high risk of false positives and/or false negatives. In order to determine whether two measures ''come apart'' in an interesting way in two or more brain-damaged patients, it is important to know the degree to which the variance in one measure can be predicted by the variance in the other. The goal of this study is to introduce a statistical procedure to determine the probability of a double dissociation when the correlation between measures is taken into account. To illustrate the importance of intermeasure correlation, we compared different quantification schemes to define dissociations between tests for noun and verb naming in an unselected sample of 190 aphasic patients at a large neurological hospital in Rome. In this particular sample (which spans a broad range of severity), the correlation between noun and verb naming is high ($r = .87$, see Fig. 6). including a subset of patients who were tested but failed to produce any names on either measure. If we do not take this correlation into account, and assume independence and equivalence of means and variance, then there are striking differences between the number of dissociations that we would ex-

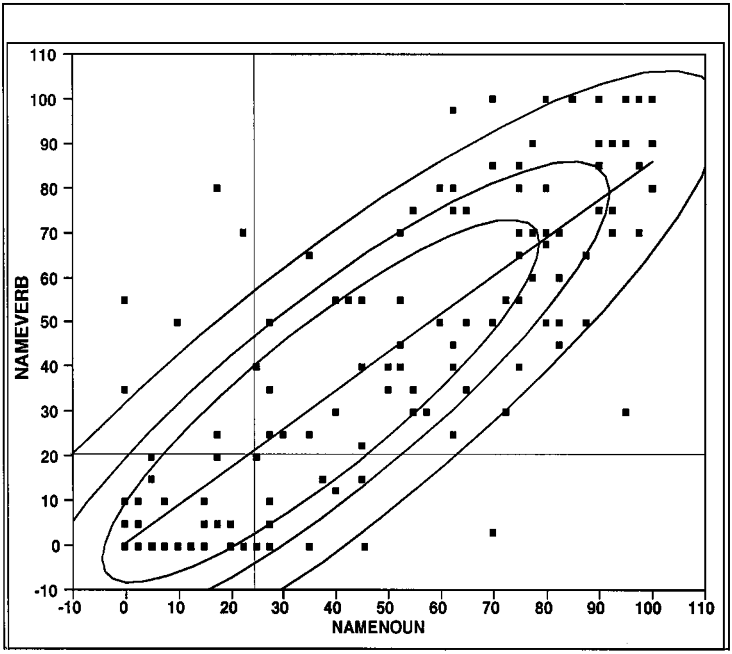

FIG. 6. Distribution of verb and noun naming scores for 190 patients.

pect on theoretical grounds and the number that is actually observed. For example, if patients were distributed independently across quartiles defined by the median on each task, we would expect 25% each to fall in the High Noun/Low Verb and High Verb/Low Noun quartiles. Instead, the actual figures observed are 5.8 and 5.3%, respectively (crossbars indicate medians in Fig. 6). If strong criteria are applied, requiring truly dissociated cases to fall 1 standard deviation above the median on one task and 1 standard deviation below the median on the other, we would expect to find five or six cases in each direction (3% each); instead, no dissociations are observed among 190 patients. To correct for the correlation between measures, we apply bivariate correlation to determine the space enclosed by 50, 70, and 90% of the population, respectively (Fig. 6). Dissociations are redefined as cases that fall outside of the selected correlation envelope, achieving numbers closer to what we would expect under assumptions of independence. Programs to quantify dissociations based on theoretical or observed correlations have been developed and are available from the first author. Implications for other aspects of aphasia research are discussed, including lesion–symptom correlations and the aphasic symptoms that do or do not correlate with theoretical dissociations under these different quantification schemes.

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Naming Tools and Using Rules: Evidence That a Frontal/Basal-Ganglia System Underlies both Motor Skill Knowledge and Grammatical Rule Use

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We investigated the hypothesis that two well-studied brain systems (see Feinberg & Farah, 1997) underlie the lexicon/grammar dichotomy (Ullman et al., 1997). In this view, frontal/basal-ganglia circuitry implicated in the learning and expression of motor and cognitive skills also underlie the acquisition and use of grammatical rules, and temporal-lobe circuits implicated in the learning and use of factual (conceptual) knowledge also underlie the learning and use of memorized words. The hypothesis predicts co-occurring word/rule and fact/skill double dissociations in patients with damage to one or the other system and similar degrees of impairment to words and facts and to skills and rules.

Lexicon and grammar, and conceptual and motor skill knowledge, were probed in patients with Parkinson's disease (PD) or Alzheimer's disease (AD). PD is associated with frontal/basal-ganglia damage, which may explain PD impairments at learning new and expressing established motor skills and at syntactic processing. In contrast, in (low-demented) PD patients there is typically little damage to temporal-lobe structures, and word and fact use remain relatively spared. AD is associated with temporal-lobe damage, which may explain AD impairments at learning new words and facts and at using established ones. In contrast, there is a relative sparing of frontal/basal-ganglia structures, learning new and using established motor and cognitive skills, and syntactic processing (see Feinberg & Farah, 1997).

Testing for grammar/lexicon dissociations has been problematic, because tasks probing lexicon and grammar usually differ in ways other than their use of the two capacities. Therefore grammar and lexicon were probed with English regular and irregular past tense. Regular forms (e.g., play–played) require an -*ed*-suffixation rule, whereas irregulars (dig–dug) undergo largely arbitrary transformations and are memorized in the lexicon. Crucially, regulars and irregulars are matched in complexity (one word), meaning (past), and syntax (tensed) (Pinker, 1991).

A previous study of regular and irregular past-tense processing in PD and AD patients probed motor skills with a task requiring skilled movement and facts with a fact retrieval task (Ullman et al., 1997). The predicted regular/irregular double dissociations and regular/skill and irregular/fact associations were obtained. However, the tasks probing skill and fact use differed in multiple ways other than the skill/fact distinction, precluding direct comparisons of the two types of knowledge.

In the present study the skill/fact distinction was tested by asking subjects to name pictures of two types of objects: (1) tools and other manipulated objects and (2) natural and man-made objects that are not normally manipulated. Knowledge of both types depends upon factual information (e.g., what a tool is used for), but only manipulated objects involve motor skill knowledge (i.e., how to use them). The naming of both object types has been linked to temporal-lobe structures, but only naming tools is associated with left frontal motor regions (e.g., Damasio et al., 1996; Martin et al., 1996).

Method. Twenty-six low-demented PD and 21 AD patients were asked to produce past tenses of 16 irregular, 20 regular, and 20 novel (plag–plagged) verbs and to name pictures of 22 manipulated objects (e.g., pencil) and of 20 natural and man-made objects that are not normally manipulated (e.g., beaver, house). They were also asked to carry out skilled movements with left and right limbs and to orally retrieve factual knowledge about the real world.

Results. Across the 26 PD patients, right-side motor skill deficits correlated significantly with errors inflecting novel and regular ($p < .01$) but not irregular (n.s.) verbs (in all correlations, dementia scores partialed out and p values one-tailed). Novel and regular verb inflection correlated with performance at naming manipulated ($p < .05$) but not nonmanipulated (n.s.) objects. In contrast, irregular verb inflection correlated with performance at naming both object types ($p < .005$).

Across the 24 AD patients, fact-retrieval deficits correlated significantly with errors inflecting irregulars ($p < .05$), but not regulars or novel verbs (n.s.). Irregular verb inflection correlated with naming errors of both object types ($p < .05$), whereas regular and novel verb errors correlated with neither (n.s.). The lack of a correlation between *-ed* suffixation and manipulated object naming suggests that the variance in the latter in AD is better explained by its dependence on conceptual than on motor skill knowledge, as is indeed confirmed by the correlation between manipulated object naming and fact retrieval ($p < .05$).

Subsets of the PD patients with the most severe right-side motor skill deficits, and of the AD patients with the most severe fact-retrieval deficits, were selected for further analysis. For these subsets, interactions were found between PD/AD, on the one hand, and Regular/Irregular Inflection, Novel/Irregular Inflection, and Manipulated/Nonmanipulated Object Naming on the other ($p \leq .05$). The PD patients made more errors at producing regular and novel verbs than irregular verbs and at naming manipulated than non-manipulated objects. The AD patients showed the opposite pattern.

Conclusion. The results link grammatical rule use in *-ed* suffixation to motor skill expression, to motor skill knowledge in naming tools, and to left frontal/basal-ganglia circuits. They link memorized word use in the production of irregular past tense forms to fact retrieval, to conceptual knowledge in naming objects, and to temporal-lobe regions. The findings support the view that the distinction between a frontal/basal-ganglia ''procedural memory'' system for motor and cognitive skills, and a temporal-lobe ''declarative memory'' system for conceptual knowledge, extends to grammar and lexicon.

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