Brain and Language **77,** 241–265 (2001)
doi:10.1006/brln.2000.2441, available online at http://www.idealibrary.com on IDEAL®

Phonologically Related Lexical Repetition Disorder: A Case Study

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Errors of repetition in aphasia are most often nonword substitutions. Phonologically related lexical errors, or formal errors, are real-word substitutions that overlap with target words in sound. In the present research we present the case of an aphasic patient, MMB, who produced an unusually high rate of formal paraphasias in repetition. Six experiments were conducted to investigate the combination of impairments contributing to MMB's pattern of repetition and to test the predictions made by two theories of formal errors. MMB's formal errors in repetition were influenced by target frequency, but not by target length or imageability. Formal errors tended to be more frequent than their targets and showed greatest phonological overlap with targets at initial consonant. These findings provided partial support for Martin and Saffran's fully interactive spreading activation account of formal errors and did not support Blanken's phonological interactive encoding account. In Experiment 6, the effect on repetition of increasing auditory verbal short-term memory (AVSTM) demands was examined using a paired word repetition experiment. Under these conditions, MMB produced semantic paraphasias for the first time, providing strong support for the Martin–Saffran hypothesis that phonologically related, and semantic, lexical repetition disorders lie on a continuum of severity moderated by the degree of AVSTM impairment.

Key Words: repetition disorder; word substitutions; formal paraphasias; conduction aphasia.

INTRODUCTION

Repetition errors in aphasia are heterogeneous and may result from impairment to one or several language processes such as comprehension, assembly, or output. Nonword productions that do not share any overt relationship with the target (e.g., arm → bis; happy → falech) are called neologisms and are common in Wernicke's aphasia (Buckingham & Kertesz, 1976; Kertesz, 1976; Kertesz & Benson, 1972). Non-

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This research was supported by a Doris Anderson postdoctoral fellowship from the Lawson Research Institute awarded to the first author. The authors thank Nadine Martin and one anonymous reviewer for helpful comments on an earlier version of this article.

0093-934X/01 $35.00

word productions that share one or several phonemes with the target (e.g., arm → arn; happy → abby) are often referred to as phonemic paraphasias. Phonemic errors can involve omissions, insertions, or transpositions of phonemes and syllables and are the most typical kind of error produced by conduction aphasics (Dubois, Hécaen, Angelergues, de Chatelier, & Marcie, 1964; Goodglass & Kaplan, 1972; Kohn, 1984) and patients with phonologically based STM impairment (Vallar & Shallice, 1990).

Less common but intriguing paraphasias are real-word substitutions, related to the target by meaning or form. Word substitutions related to the target by phonological form (arm → art; happy → sloppy) are called formal or phonologically related lexical paraphasias. Formal errors are similar to malapropisms, which are phonologically based word substitutions occurring as spontaneous slips of the tongue in normal speakers (Fay & Cutler, 1977). The low rate of formal, compared to phonemic, errors in aphasia led Butterworth (1979) among others to suggest that the lexical status of the former may result largely from chance factors. This view assumes that the same (sublexical) mechanisms underlying phonemic errors lead to formal errors, which just happen to result in the production of legal word forms. Thus, Butterworth (1979) referred to whole-word substitutions sharing phonological overlap with the target as ‘‘jargon homophones.’’ However, this view necessarily predicts small numbers of formal paraphasias in any one patient’s error corpora, and several authors have since presented cases in which ratios of formal errors far exceeded what could be predicted from estimates of chance occurrences (Best, 1996; Blanken, 1990, 1998; Martin & Saffran, 1992).

The majority of research conducted on real-word errors in aphasia has focused on semantic paraphasias (Howard & Franklin, 1988; Katz & Goodglass, 1990; Martin & Saffran, 1992; Michel & Andreewsky, 1983). The tendency toward a high proportion of semantically related word substitutions (arm → leg; happy → content) forms part of the symptom complex called ‘‘deep dysphasia,’’ a disorder in repetition that is parallel to the disorder of deep dyslexia in reading. Patients with deep dysphasia tend to produce formal paraphasias in addition to semantic word substitutions, although the proportion of one error type to another varies across individual cases (Howard & Franklin, 1988; Katz & Goodglass, 1990; Martin & Saffran, 1992; Michel & Andreewsky, 1983; Morton, 1980).

Recently, two theories have been proposed to account for formal errors in naming and repetition (Blanken, 1998; Martin & Saffran, 1992), based on principles from Dell’s (1986) interactive spreading activation language model. Dell’s model was developed as a theory of language production, but has since been extended to input processes (Martin & Saffran, 1992; Martin, Saffran, & Dell, 1996). Martin and Saffran (1992) have attempted to explain formal errors in repetition with reference to the input model. Dell’s model assumes phonological, lexical, and semantic levels of representation of a word to be repeated or read. Representations of an item to be repeated or read are assumed to proceed serially in automatic cascade through a phonological-lexical-semantic network. Feedforward and feedback mechanisms serve to stabilize representations and are intended to facilitate output of the lexical target. In the processes of spreading activation to the lexical target, feedforward processes also prime other lexical nodes, related semantically and phonologically to the target. Two further components specify the fully interactive nature of Dell’s language model. First, the language system is thought to exploit all stimulus information available, even if that information is not strictly necessary to the performance of a particular task. The consequence of this supposition for repeating or reading a word is that activation from primed phonological nodes is assumed to spread to semantic in addition to lexical nodes. Second, the Dell model construes network activation as bidirectional, with nodal connections running bottom-up as well as top-down, resulting in feedback whereby, in repetition, phonological units receive input from activated lexical units and lexical units get feedback from activated semantic units. Two parameters govern the nature of the final verbal output: the strength of nodal connections and the rate at which nodes decay.

Martin and Saffran's (1992) theory actually provides an account of both semantic and phonologically based lexical (formal) repetition errors. The authors suggest that lexically based disorders of repetition result from an accelerated rate of decay of nodes in the phonological-lexical-semantic network. Deep and phonologically based lexical forms of dysphasia are seen to lie on a continuum of severity moderated by the degree of damage to auditory verbal short-term memory (AVSTM). Deep dysphasia is thought to be associated with a ''pathologically accelerated rate of decay of nodes'' (their patient, NC, had an original AVSTM capacity of 1 item), whereas phonologically based lexical dysphasia is associated with a prominent, but less severe restriction (NC's AVSTM capacity improved to two to three items when he began to display more formal than semantic errors). The theory of lexical errors proposed by Martin and Saffran is referred to as the ''fully interactive activation hypothesis.''

The fully interactive activation hypothesis assumes that feedforward processes spread activation from phonological nodes to the corresponding lexical target as well as to phonologically similar lexical competitors. A reduced capacity of AVSTM increases the lexical target's rate of decay and its trace begins to fade before the arrival of feedback from phonological nodes. The consequence of the instability of the adequately primed lexical target is that when reverberating feedback arrives from phonological nodes, the weakly maintained target is vulnerable to competition from phonologically related lexical competitors primed during initial feedforward processes. A formal error results when a word with higher resting activation (higher frequency) is selected for output and transferred to speech production systems.

A different account of formal errors is proposed by Blanken (1998), who suggests they can be traced back to impairment of the speech production system itself, causing errors in phonological encoding for production. Blanken's theory assumes that formal errors retain their lexical status because the process of phonological encoding is itself bidirectionally interactive in the sense that, during preparation for output, phonetic (segmental/metric) units send activation back to lexical units. However, because phonological encoding systems are damaged, some of the segmental units they reverberate back to lexical nodes are incorrect. A formal error occurs when the combined feedback from incorrectly and correctly computed segmental units delivers stronger priming to a phonologically related lexical competitor than the lexical target. Thus, formal errors are seen to result from difficulties in phonological encoding as opposed to a decreased capacity to maintain lexical representations. Blanken's theory of formal errors is referred to as the ''phonological interactive encoding hypothesis.''

The fully interactive and phonological interactive encoding hypotheses offer different predictions about the influence of phonological, lexical, and semantic variables on the production of formal errors in repetition. The major prediction of the fully interactive activation hypothesis is that formal errors in repetition should result more often in response to low-frequency targets. In terms of phonological influences, the theory predicts that errors will resemble targets most at the initial consonant. In terms of semantic influences, the theory predicts imageability effects on formal errors and preservation of the target's grammatical class.

The phonological interactive encoding hypothesis maintains that formal errors result from damage to speech production systems and therefore predicts strong phonological effects on the occurrence of formal errors in repetition. The sole prediction of the phonological encoding hypothesis is a greater proportion of formal errors on longer targets than shorter targets. The phonological interactive encoding hypothesis does not predict frequency effects because formal paraphasias are construed as essentially sublexical errors in production, despite the model's assumption of sound–lexical interactions. Similarly, it does not predict preservation of the target's grammatical class because no form–meaning interactions in production are assumed.

This article focuses on a patient who produced a high proportion of formal paraphasias in repetition. Background testing and a series of experiments were carried out to probe the nature of her underlying impairments and to test the predictions of the fully interactive activation and phonological interactive encoding hypotheses.

CASE DESCRIPTION

MMB suffered a left-hemisphere stroke in 1998. MRI revealed an infarct in posterior left MCA territory involving the inferior parietal lobule and the posterior superior temporal area. One month following the stroke, MMB produced fairly fluent paraphasic speech without verbal apraxia or anarthria. On the Western Aphasia Battery (WAB; Kertesz, 1982), MMB demonstrated severe deficits in repetition, with mild impairment of auditory comprehension and naming. MMB produced formal paraphasias in repetition (pipe → pump). MMB's score profile on the WAB fit a classification of conduction aphasia. She was also surface dyslexic, showing an inability to read irregular words. Reassessment with the WAB 1 year following stroke indicated improvement in fluency, repetition, naming, and comprehension. However, MMB continued to demonstrate impaired repetition, characterized by a high proportion of formal paraphasias. On repetition of short phrases and sentences, MMB's responses were rarely complete although the semantic gist of items tended to be retained. She also remained surface dyslexic. Research with MMB was a carried out over a period of 4 months, beginning 1 year following her stroke.

BACKGROUND INVESTIGATION

Repeating High-Frequency Regular Words

MMB's repetition was tested on a set of 40 two- to three-syllable, regular words of high frequency taken from the Alexia Battery (Bub, Black, Howell, & Kertesz, 1987). Words were presented from an audiotape to avoid lip cues. MMB was asked to repeat each word immediately following presentation. One repeat presentation per trial was allowed if MMB reported that she ''could not hear'' a word. Responses were recorded on audiotape. The first complete response was subsequently scored. Table 1 summarizes scoring system used to classify errors in the present research.

TABLE 1

Criteria for Classification of MMB's Error Responses

Formal paraphasia (F): Real word error sharing two or more phonemes with the target, or sharing one phoneme at the same segmental position. In addition, these errors are unrelated to the target semantically (e.g., Truck → Table).

Semantic paraphasia (S): Real word semantically related to the target but unrelated to the target phonologically (e.g., Equipment → Mechanic).

Derivative (D): Real word that differs from the target only in terms of its suffix (e.g., Pacifism → Pacifist).

Unrelated lexical (UL): Real word unrelated to the target semantically or phonologically (e.g., Advantage → Individual).

Phonemic paraphasia (P): Nonword sharing two or more phonemes with the target, or sharing one phoneme at the same segmental position (e.g., Feudal → Rutal).

No response (NR): No attempt to repeat target.

Formal errors (here and throughout the present research) were classified according to Blanken's (1998) criteria of two or more shared phonemes with the target (e.g., Pudding → Plastic) or one shared phoneme also sharing segmental position (e.g., Truck → Table).

Results. MMB responded to all words, repeating correctly .68 of targets. Her most common error was the formal paraphasia (.21 of responses). Remaining paraphasias were phonemic (.05), derivate (.03), and unrelated lexical (.03). There was a significant difference in the proportions of repetition error types, $\chi^2(3) = 12.25$, $p < .007$.

Repeating pseudowords. All patients reported to produce high proportions of semantic and/or formal paraphasias in repetition have demonstrated increased impairment in the ability to repeat pseudowords relative to words. MMB was asked to repeat 60 high-frequency, high-imageability words, and 60 pseudowords. Words and pseudowords were matched for initial letter, word length, and number of syllables. Responses were tape recorded and subsequently scored by one of the experimenters and a psychometrist. MMB repeated correctly .80 of the real words but only .17 of the pseudowords, and this difference was significant, $\chi^2(1) = 42.3$, $p < .001$.

Reading pseudowords. At a separate testing session, MMB was asked to read the same words and pseudowords to explore her ability to assemble output phonology. MMB read accurately .95 of the real words and .93 of the pseudowords. MMB's significantly better reading than repetition of pseudowords suggests her ability to assemble output phonology from visual input was relatively intact.

Repeating and reading words from different grammatical classes. Grammatical category effects in repetition make up part of the symptom complex of deep dysphasia. A ''parts of speech effect'' refers, minimally, to better repetition of nouns than functors (which are highly abstract). MMB did not make any semantic errors on repetition of single words. Nevertheless, the possibility of grammatical class effects in repetition could not be ruled out.

MMB was asked to repeat lists of nouns, adjectives, verbs, and functors. All words were high frequency [greater than 100 per million in the Kucera & Francis (1967) count] and low imageability [concreteness rating of ≤ 3 in the norms of Paivio, Yuille, & Madigan (1968)] to approximate the abstractness of functors. There were 40 words in each grammatical class, matched for number of syllables. Words were presented in blocks. MMB repeated correctly .85 of adjectives, .83 of verbs, .78 of nouns, and .70 of functors. The differences MMB's repetition accuracy of words from different grammatical classes were not significant, $\chi^2(3) = 3.1$, $p > .371$. There was also no significant effect of grammatical class in MMB's reading (nouns, verbs, and functors = .93 correct; adjectives = .88 correct). Thus MMB did not exhibit one of the cardinal features of deep dysphasia.

Semantic Processing of Nonverbal Material

The picture condition of the Pyramids and Palm Trees Test (Howard & Patterson, 1992) was administered to assess MMB's semantic processing of nonverbal material. MMB's score of 48 (92%) was above the cutoff for norms established on brain injury patients (>90%; Howard & Patterson, 1992), suggesting that MMB's semantic representations are relatively intact and that she retains the ability to access those intact representations from visual input.

In summary, MMB produces a high proportion of formal paraphasias in repetition, and she cannot repeat pseudowords. She is not deep dysphasic because she does not make semantic errors or show an effect of grammatical class in repetition.

EXPERIMENT 1

Accuracy of word repetition can be influenced by target length, frequency, and imageability. In this experiment, we examined the influence of each of these variables on the accuracy of MMB's single-word repetition. MMB was asked to read the same words at a later date to explore the influence of the same variables on her word production from visual input. The influence of target regularity on reading (and repetition) was also examined because MMB is surface dyslexic.

Method

The stimuli were 240 nouns varied for number of syllables (one to three), frequency, and imageability. High-frequency nouns had ratings $\geq$100 per million, and low-frequency nouns had ratings $\leq$20 per million (Kucera & Francis, 1967). High-imageability nouns had concreteness ratings $\geq$6, and low-imageability nouns had concreteness ratings $\leq$3 (Paivio, Yuille, & Madigan, 1968). Words were arranged into four groups of 60: high frequency/high imageability, high frequency/low imageability; low frequency/high imageability, and low frequency/low imageability. In addition, some of the nouns had irregular spellings ($N = 48$). Irregular nouns were distributed evenly among the four groups.

In the repetition task, words were presented from an audiotape to avoid lip cues, and MMB was asked to repeat each word immediately following presentation. One month following the repetition task, MMB was asked to read the same 240 words. Responses to both tasks were recorded on audiotape. The first complete response was scored independently by one of the experimenters and a psychometrist (both native speakers of English). Error responses were classified according to the same criteria given in Table 1. Following Blanken (1990), the influence of word length, frequency, and syntactic class were also assessed through examination of individual target → formal error pairs. Frequency values of formal paraphasias were obtained from Kucera and Francis (1967). Only errors with a frequency difference of more than five were scored as unequal (Blanken, 1998).

Results and Discussion

MMB repeated accurately .67 and read accurately .86 of the 240 words, indicating superior verbal production from visual than auditory input. In repetition, the most common error was a nonresponse (.11 of items), suggesting difficulties in phonological input processing. As was the case in the background investigation, MMB's most frequent response error was the formal paraphasia (.10 of items), followed by phonemic paraphasias (.03 of items). Once again, MMB's rate of production of formal compared to phonemic paraphasias (three times as many in this experiment) demonstrates a clear ''lexical bias'' in repetition. Some of MMB's nonword errors were regularizations (Hour → Hower; .08 of irregular words). The remainder of MMB's paraphasias were word substitutions, including derivatives (e.g., photograph → photographs) and unrelated lexical errors (e.g., advantage → individual). MMB produced one semantic (perseverative) error (professor → NR; effort → teacher) and one mixed error (microscope → periscope). None of MMB's errors were neologisms.

Table 2 gives the proportions of correct responses in repetition and reading as a function of target length, frequency, regularity, and imageability. MMB's repetition accuracy was affected by target frequency, $\chi^2(1) = 9.64$, $p < .002$, and imageability, $\chi^2(1) = 8.31$, $p < .003$, but not word length $\chi^2(2) = .23$, $p > .89$, or regularity $\chi^2(1) = .03$, $p > .87$.

Formal errors. The occurrence of MMB's formal paraphasias in repetition was influenced by target frequency, indicating lexical involvement in her formal errors in support of the fully interactive activation hypothesis. Significantly more formal errors were produced in response to low-frequency than high-frequency targets, $\chi^2(1) = 5.82$, $p < .05$. Figure 1 shows the percentage of repetition errors constituting formal paraphasias, phonemic paraphasias, or nonword responses as a function of frequency of the target word. Examination of the influence of target length failed to

TABLE 2
Effects of Length, Frequency, Regularity, and Imageability on the Accuracy of MMB's Responses in Repetition and Reading

	Repetition	Reading
Syllable number		
One (*n* = 87)	.80	.93
Two (*n* = 73)	.79	.86
Three (*n* = 80)	.78	.88
Frequency/imageability		
High/High (*n* = 60)	.83	.97
High/Low (*n* = 60)	.65	.90
Low/High (*n* = 60)	.62	.82
Low/Low (*n* = 60)	.48	.75
Regularity		
Regular (*n* = 192)	.68	.97
Irregular (*n* = 48)	.65	.66

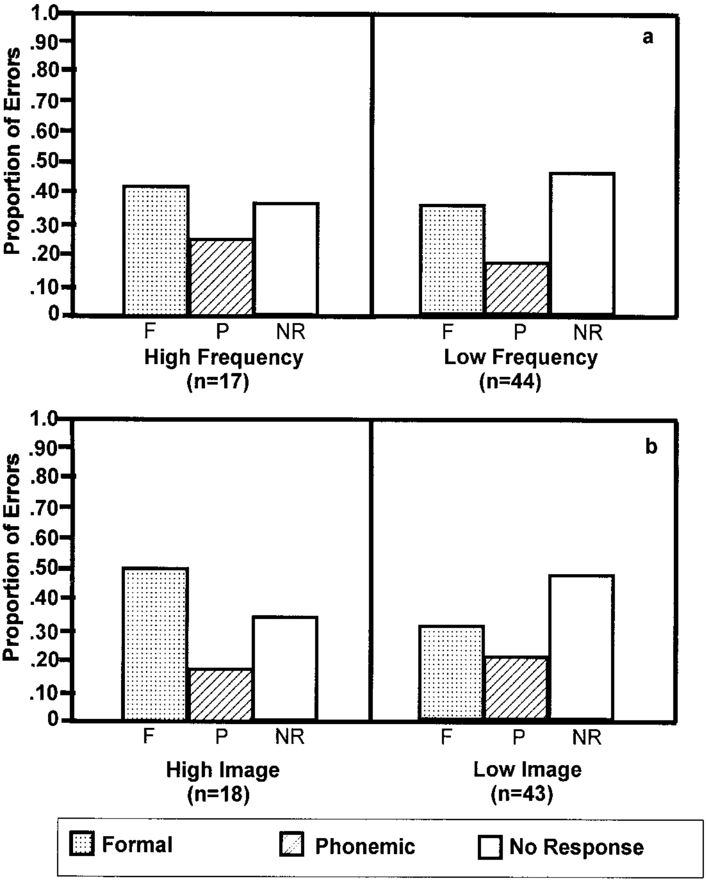

FIG. 1. Patterns of MMB's repetition errors as a function of target word's (a) frequency and (b) imageability.

find support for the phonological interactive encoding hypothesis: target length did not influence the occurrence of formal paraphasias, $\chi^2(2) = .67$, $p > .71$. Although the accuracy of MMB's responses was influenced by target imageability, this variable did not influence the occurrence of formal paraphasias, $\chi^2(1) = 1.46$, $p > .23$. Target regularity also did not influence the occurrence of formal paraphasias, $\chi^2(1) = .25$, $p > .62$.

Examination of individual target → error pairs provided limited further support of lexical involvement in MMB's formal paraphasias. Formal errors were of higher frequency than their targets in .54 of cases (lower in .33 of cases and equal in .13 of cases). However, a frequency analysis indicated that the tendency for targets to be replaced by words of higher frequency was not significant (Sign test: $N = 24$, $z = 1.09$, $p > .383$, two-tailed).

Examination of target length again failed to find support for the phonological interactive encoding hypothesis. The lengths of MMB's formal errors were remarkably preserved relative to targets; .83 of formal paraphasias were identical to targets in syllable number (.13 of errors had more syllables and .04 had fewer). A length analysis indicated no significant differences (Sign test: $N = 24$, $z = 1.00$, $p > .625$, two-tailed). The preservation of length was also evident in the total number of letters (.53 of formal paraphasias were identical to targets; .29 of errors had more and .18 had fewer letters than the target). In addition, the initial consonant was preserved in .87 of formal errors. The same tendency for greatest agreement in initial consonant in malapropisms in normal spontaneous speech has been interpreted as evidence of lexical involvement in formal paraphasias (Fay & Cutler, 1977).

Examination of syntactic class of formal errors provides support for semantic influences on MMB's formal paraphasias. The syntactic class of formal errors was preserved in .86 of cases. Nouns were replaced by verbs in only .14 of MMB's formal paraphasias. Information about a word's grammatical category is generally thought to be stored alongside its semantic properties, at the so-called ''lemma'' level (Butterworth, 1980; Fromkin, 1971; Garrett, 1976; Levelt, 1992). The fully interactive theory assumes activation of all nodes in the phonological-lexical-semantic network, including priming of nodes related to the lexical target by meaning. It therefore predicts that formal errors should tend to stay within the target's grammatical category, whereas the phonological interactive encoding hypothesis makes no such prediction because semantic influences are not assumed.

Reading. In reading, MMB produced responses to all items. The majority of MMB's errors (.44) were regularizations (pronunciation of irregular words using normal phonetic rules). The remaining eight errors were phonemic paraphasias ($>.1$ of total responses). MMB did not produce any formal paraphasias in reading. Her reading was most affected by regularity [regular words = .97 correct; irregular words = .66 correct; $\chi^2(1) = 45.6$, $p < .001$]. MMB's reading was also influenced by target frequency [high frequency = .93 correct; low frequency = .78 correct; $\chi^2(1) = 11.10$, $p < .001$], but not by imageability [high imageable = .93 correct; low imageability = .86 correct; $\chi^2(1) = 2.19$, $p > .14$] or length [one syllable = .93 correct; two syllable = .86 correct; three syllable = .88 correct; $\chi^2(2) = 2.46$, $p > .29$].

Due to the high proportion of regularizations in MMB's reading, we decided to examine potential effects of length, frequency, and imageability on the occurrence of this error type. Frequency influenced the occurrence of regularization errors [high frequency = .19; low frequency = .61; $\chi^2(1) = 11.9$, $p < .001$], as did imageability [high imageability = .28; low imageability = .53; $\chi^2(1) = 4.2$, $p < .042$]. The occurrence of regularization errors was not influenced by word length [one syllable = .28; two syllable = .36; three syllable = .28; $\chi^2(2) = 2.1$, $p > 3.51$].

MMB did not produce formal paraphasias in reading as she did in repetition. However, as with repetition, MMB's reading is most strongly influenced by lexical variables. Both target regularity and frequency influenced the accuracy of MMB's reading and her regularization errors were most often produced in response to low-frequency targets.

EXPERIMENT 2

Reduced span capacity of auditory verbal short-term memory (AVSTM) has often been reported in cases of disordered repetition (Blanken, 1998; Howard & Franklin, 1988; Katz & Goodglass, 1990; Martin & Saffran, 1992). In some cases of deep dysphasia, visual short-term memory (STM) has been reported to be relatively spared (Katz & Goodglass, 1990; Martin & Saffran, 1992). In this experiment, we examined MMB's auditory and visual STM capacities. The effect of word length on MMB's span capacity was also examined. In normal subjects, word length is negatively correlated with span capacity (Baddeley, Thompson, & Buchanan, 1975). However, patients with STM-based repetition impairments (Shallice & Vallar, 1990), and one deep dysphasic patient who has been tested (Martin et al., 1996), failed to show the typical effects of word length on span, suggesting deficient phonological representations.

Method

Digit span was assessed with a pointing response to examine STM independently of impaired repetition. MMB was asked to point to corresponding visual digits in sequential order immediately following presentation. Response cards displayed 1 of 10 different arrangements of printed numbers (1–9) and were rotated every three trials to minimize the opportunity for spatial encoding to aid recall (Martin et al., 1996). In addition, response cards were made visible only following digit presentation. In the auditory condition, digit strings (1–9) were presented by audiotape to avoid lip cues. In the visual condition, printed digit strings were presented on individual test plates.

MMB was also asked to repeat lists of 20 high-frequency, concrete words varied for syllable length (one vs two) to assess the effects of word length on her span. There were four lists: two words/one syllable (40 words), two words/two syllables (40 words), three words/one syllable (60 words), and three words/two syllables (60 words).

Results and Discussion

MMB's auditory–verbal digit span was two to three numbers. She responded correctly in sequential order on 1.0 of the two-digit trials, .78 of the three-digit trials, and .43 of the four-digit trials. Figure 2 presents accuracy ratios of MMB's responses as a function of digit position within a string. MMB's serial position curve for digits is characterized by loss of recency (end of list information). Normal subjects typically show significantly greater retention of the last few items compared to earlier items ''the recency effect'' (e.g., Waugh & Norman, 1965; Glanzer & Cunitz, 1966), whereas the majority of patients with STM-based impairments show reduced recency effects on supraspan lists of unrelated verbal items (Shallice & Vallar, 1990). MMB's performance on an AVSTM task using a pointing response ensures that her impaired AVSTM is not attributable to defective speech output.

MMB's visual STM digit span (three to four digits) was superior to her auditory span (two to three). MMB responded correctly in sequential order on 1.0 of the two- and three-digit trials, .87 of the four-digit trials, and .51 of the five-digit trials. Normal subjects show greater span from auditory than visual presentation (the ''modality

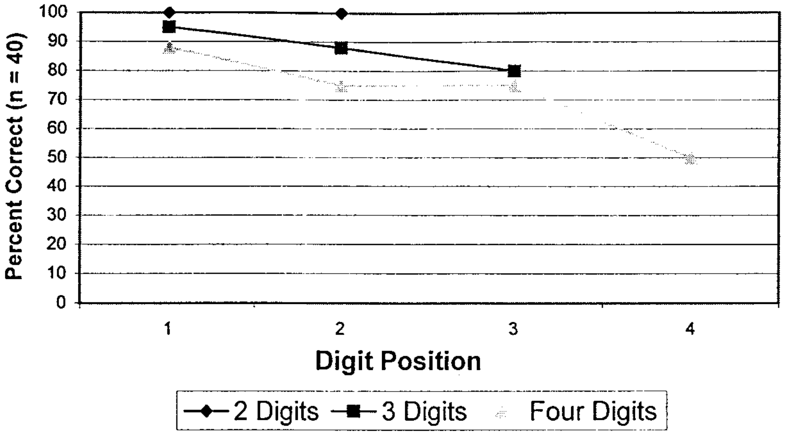

FIG. 2. MMB's serial position curve for digits.

effect'') (e.g., Conrad, 1964). The inverse modality effect—greater visual than auditory span for verbal material—is characteristic of patients with primary disorders of STM (Shallice & Vallar, 1990) and has sometimes been reported in deep dysphasia (Martin et al., 1996).

On the word span test, MMB repeated correctly in serial order .40 of the items on the two-word/one-syllable list, and .45 of the items on the two-word/two-syllable list. Her performance was at floor for three word lists. MMB repeated correctly .10 of the items on the three-word/one-syllable list and .5 of the items on the three-word/two-syllable list. The differences between MMB's accuracy rates on two- and three-syllable words were not significant for either two-word lists or three-word lists (p = .05). MMB's failure to show the typical effects of word length on span suggests decreased reliance on phonological STM in the maintenance of lexical material.

EXPERIMENT 3

In addition to formal paraphasias, MMB produces a high rate of phonemic errors in repetition. Impairment of phonological discrimination is likely a contributing factor in phonemic paraphasias. Although damage to phonological input systems cannot, by itself, cause lexical substitutions, it may contribute to them. The interactive activation hypothesis suggests that damage to systems of auditory discrimination contributes to formal paraphasias when combined with restricted AVSTM capacity because subjecting already unstable phoneme strings to an increased rate of decay further decreases the lexical target's typical advantage relative to its phonologically related lexical competitors. In this experiment, we examined MMB's phonological discrimination capacity and explored the effects of increasing AVSTM demands on that capacity.

Method

A minimal-pair judgment task (Martin & Saffran, 1992) was administered. The minimal pair task provides an assessment of the ability to discriminate both words and pseudowords from closely matched letter strings. The subject decides whether word and pseudoword pairs are identical. There are three conditions, which vary the interval between presentation of pairs. The stimuli are 40 identical word pairs, 40 identical pseudoword pairs, 40 phonologically dissimilar word pairs, and 40 phonologically dissimilar pseudoword pairs. Items are one or two syllables. Half of the word pairs consist of concrete words and half consist of abstract words. Phonologically dissimilar pairs are created from identical pairs and differ by one phoneme from their identical pair counterparts. The test is presented in 5 pseudorandomized blocks of 32 items, with the restriction that identical members and nonmatching counterpart pairs do not appear in the same block.

In a no-delay condition, the second word in a pair is presented immediately following presentation of the first word. In an unfilled delay condition, the second word in a pair is presented 5 s following presentation of the first word. In a filled delay condition, the second word in a pair is also presented 5 s following presentation of the first word. In this condition, the subject and experimenter count aloud from 1 to 5 during the delay interval to prevent subject rehearsal. Items were presented from an audiotape recording to prevent lip cues. MMB indicated her responses by nodding (''yes'' or ''no'').

Results and Discussion

Table 3 presents the accuracy of MMB's responses to similar and dissimilar word and pseudoword pairs under three delay conditions. She was able to identify similar pairs with a high degree of accuracy (.96), but significantly less able to discriminate dissimilar pairs (.81), $\chi^2(1) = 52.17$, $p < .001$, suggesting less than normal ability to discriminate between closely matched phonological strings.

MMB's performance was not affected by item lexicality or concreteness. MMB's accuracy rates on the minimal pair judgment auditory discrimination task were .89, .78, and .71 in the no-delay, unfilled-delay, and filled-delay conditions, respectively. The average scores of a group of 22 fluent aphasic patients of various classification and severity on the no-delay and filled-delay conditions (no data obtained for the unfilled-delay condition) were .94 ($SD = .07$), and .85 ($SD = .12$), respectively (Martin & Saffran, 1997). Thus, MMB demonstrates impaired phonological input processing relative to other aphasic patients. The accuracy of MMB's responses varied significantly as a function of delay condition, $\chi^2(2) = 7.17$, $p < .028$. MMB's sig-

TABLE 3
Auditory Discrimination of Word and Nonword Pairs: Proportions of Pairs Judged Correctly as Same or Different under Three Delay Conditions

	Testing condition	
Delay condition/stimulus	Same	Different
No delay (n = 20 per cell)		
Words		
Abstract	95	65
Concrete	100	80
Nonwords		
Abstract	95	75
Concrete	95	65
Unfilled 5-s delay (n = 20 per cell)		
Words		
Abstract	95	50
Concrete	95	60
Nonwords		
Abstract	80	75
Concrete	85	75
Filled 5-s delay (n = 20 per cell)		
Words		
Abstract	90	50
Concrete	95	65
Nonwords		
Abstract	90	45
Concrete	90	45

nificantly poorer performance in the delay conditions confirms that systems supporting the processing of phoneme strings are subject to rapid decay of information over time.

EXPERIMENT 4

The finding that MMB's repetition is strongly influenced by target frequency raises the possibility that her high rate of formal paraphasias could be the result of impaired or lexical knowledge. If this were the case, then MMB's formal paraphasias in repetition could be attributable to errors in lexical retrieval, as opposed to accelerated decay of lexical nodes, as suggested by the fully interactive activation hypothesis. In this experiment, a lexical decision test and two measures of lexical comprehension were administered to explore this possibility.

Method

A lexical decision task was administered to identify possible effects of target length, frequency, regularity, and imageability on MMB's lexical access. Stimuli were 120 nouns from the repetition task and 120 pseudowords derived from those nouns. Words from the repetition experiment were used to enable comparison of responses in repetition and lexical decision to the same items. Pseudowords were created from words by changing one phoneme. The position of the replaced phoneme was varied within words. Two groups of items, each consisting of 60 words and 60 pseudowords, were created so that pseudowords could be presented separately from their word derivative counterparts. The two groups of 120 items were presented in separate testing sessions.

Items were presented from an audiotape to avoid lip cues. MMB was asked to nod ''yes'' or ''no'' immediately following presentation of each word. The lexical decision test was administered visually 1 month following auditory presentation to examine possible effects of input modality. Stimuli were typed in vertical columns with the ordering of items randomized within groups. The two lists of items were presented in separate testing sessions, as with auditory presentation. MMB was asked to place a pencil mark beside real words.

The Peabody Picture Vocabulary Test (PPVT) (Form L) (Dunn & Dunn, 1981) was administered to assess MMB's level of lexical comprehension. The PPVT is a 175-item test of lexical comprehension in which subjects are asked to select from four drawings the one corresponding to the word spoken by the experimenter. Target words range from very high to very low frequency.

The Lexical Comprehension Test from the Philadelphia Comprehension Battery (Saffran, Schwartz, Linebarger, Martin, & Bochetto, 1989) was administered to explore the effects of phonological and semantic confusability on MMB's auditory lexical comprehension. Like the PPVT, the 44-item Lexical Comprehension Test involves selecting from four drawings the one corresponding to the word spoken by the experimenter. The Lexical Comprehension Test contains sections in which distracters are related to target words phonologically (snake → steak) or semantically (banana → strawberry). Scores are compared with performance on a third section in which distracters are related to target words perceptually (e.g., pen → tie).

Results and Discussion

MMB responded correctly to .87 of items in the lexical decision test, indicating relatively intact lexical access (compared to .67 in repetition). Her errors were divided evenly between words (16) and pseudowords (16). Frequency influenced accuracy [high frequency = .93 correct; low frequency = .80 correct; $\chi^2(1) = 4.62$, $p > .032$], but imageability did not [high imageability = .83 correct; low imageability = .90; $\chi^2(1) = 1.15$, $p > .283$]. MMB performed flawlessly (1.0) when the same items were presented from the visual modality.

A basic assumption of the fully interactive activation hypothesis (and the phonological interactive encoding hypothesis) is that lexical errors in repetition require adequate priming of lexical nodes. Practically, this assumption implies that formal paraphasias should not be produced in response to words that do not exist within, or cannot be accessed from, an individual subject's lexicon. This assumption was tested by reexamining responses to individual nouns *in repetition* that MMB's responded to incorrectly in the lexical decision task (words she incorrectly identified as nonwords). A total of 80% of words MMB incorrectly identified as nonwords in the lexical decision task were either not reproduced or produced as phonemic paraphasias in the repetition task. Only 20% of these words ''unknown'' to MMB were produced as formal errors in repetition. Although this finding is generally in line with the notion that formal paraphasias tend to involve adequate priming of lexical nodes, it indicates that they can be produced without such priming.

On the PPVT, MMB reached ceiling performance on the 172nd item. She received a raw score of 158, a standard score of 99, and a percentile rank of 48, corresponding to the Average range for her age cohort. MMB's errors came on low-frequency items.

On the Lexical Comprehension Test, MMB received perfect scores on sections in which distracters were perceptual (16/16) and phonological (12/12). MMB made one error on the semantic distractor section (15/16) on a low-frequency target word (trombone).

The finding in the present experiment that MMB's lexical comprehension is only mildly impaired suggests that her high rate of word substitutions in repetition is unlikely to result from errors in lexical retrieval (i.e., accessing of incorrect lexemes).

EXPERIMENT 5

Background investigation with the picture condition from Pyramids and Palm Trees Test revealed that MMB's semantic representations were intact and that she retained the ability to access those representations from visual input. However, it remained possible that her ability to access semantic representations from auditory input was damaged and that this contributed to her repetition impairment. Another possibility was that systems for accessing semantic representations from auditory input were intact, but that MMB was unable to assemble output phonology from those representations. In this experiment, we investigated each of these possibilities with tests of auditory definitions and naming, respectively.

Method

MMB was asked to define the list of 240 words to assess her ability to process the semantic characteristics of spoken words and to determine the effects of length, frequency, regularity, and imageability on her auditory lexicosemantic comprehension. Here we were concerned with MMB's knowledge about a word's meaning and not her ability to register the word auditorally. Therefore, word presentation was repeated at MMB's discretion. The maximum number of repetitions of any one item MMB requested was 4. Words were presented from audiotape to avoid lip cues and MMB's responses were recorded on audiotape.

Responses were scored as correct or incorrect, with reference to dictionary definitions and with emphasis on whether MMB's response indicated general comprehension, irrespective of grammaticality or completeness. For example, ''Below the main house'' was scored correct for ''Basement,'' but ''Dedication'' was scored incorrect for ''Honour.'' Responses to individual nouns *in the repetition task* that MMB responded to incorrectly in the definition task (words she could not define or defined incorrectly) were then reexamined to assess the degree to which her ability to repeat a word depended on knowing its meaning.

Naming was tested with the Boston Naming Test (Kaplan, Goodglass, & Weintraub, 1983) and the Philadelphia Naming Test (PNT; Roach, Schwartz, Martin, Grewal, & Brecher, 1996). The PNT was administered to examine potential effects of target frequency and length on MMB's naming. The PNT consists of 175 drawings corresponding to high-, medium-, and low-frequency nouns, which range in length from one to four syllables. MMB was encouraged to respond with a single word as soon as possible following item presentation. Her responses were tape recorded. As with repetition, MMB's first complete response was transcribed. Responses were then coded by a speech-language pathologist from our hospital (KS).

Results and Discussion

MMB proved better at defining words (.80 accurate) than she had been at repeating them (.67 correct). The vast majority of MMB's errors were nonresponses (''I don't know''). The accuracy of MMB's definitions was affected by target frequency [high frequency = .88 correct; low frequency = .68 correct; $\chi^2(1) = 12.81$, $p < .001$] and by imageability [high imageable = .92 correct; low imageable = .64 correct; $\chi^2(1) = 26.37$, $p < .001$]. Neither regularity [regular = .82 correct; irregular = .78 correct; $\chi^2(1) = .814$, $p > .367$] nor length [one syllable = .85 correct; two syllable = .78 correct; three syllable = .75 correct; $\chi^2(2) = 2.77$, $p > .250$] affected definition accuracy.

Reexamination of MMB's responses on the *repetition* task reveals that she did not respond, or produced paraphasic responses, to .50 of words defined incorrectly in the present semantic task. This is significantly lower than her overall repetition accuracy (.67) [$\chi^2(1) = 6.64$, $p < .01$] and suggests at least partial reliance on semantic knowledge in repetition. However, no specific error pattern in repetition emerged on words defined incorrectly in the semantic task. Thus, although the accuracy of MMB's repetition depends on knowledge about a word's meaning, a lack of semantic knowledge does not increase the likelihood that she will produce formal errors, per se. This is in line with the finding that imageability influences the accuracy of MMB's repetition, but not the occurrence of her formal errors.

On the Boston Naming Test, MMB named 48 of 60 pictures correctly without cues and an additional 2 items following phonemic cues. MMB's overall score of 51 ranked at the 40th percentile for her age and education group. MMB's naming was therefore not significantly impaired. Errors came on less frequent items. Nonresponses accounted for eight of MMB's errors. MMB committed three phonemic paraphasias and one semantic paraphasia.

On the PNT, MMB's scored 92% correct on first complete response. Comparison with normative data collected by Roach et al. (1996) on 30 non-brain-damaged adult controls (*M* = 96% correct on first complete response, *SD* = 6.9) indicates that MMB's naming is not significantly different from normal. MMB's naming accuracy was not influenced by frequency or syllable number. The majority of MMB's errors were phonemic (.36), followed by semantic (.29) and mixed (.14). MMB's remaining errors were distributed evenly among formal paraphasias, nonresponses, and fragmentary (monosyllabic or self-interrupted) responses.

MMB shows relatively little damage to systems involved in semantic processing from auditory input or to systems involved in the assembly of output phonology from semantics. Her high rate of formal paraphasias in repetition is not attributable to either of these variables.

EXPERIMENT 6

Martin and Saffran (1992) and Martin et al. (1996) have suggested that the repetition disorders of deep dysphasia and phonologically related lexical dysphasia (predominant rate of formal errors) lie on a continuum of severity, mediated primarily by degree of AVSTM impairment. The authors reported that as the AVSTM span capacity of NC improved, the quality of his repetition errors changed (''resolved'') from predominantly semantic to mostly formal paraphasias. Martin et al. (1996) demonstrated the reemergence of semantic errors in repetition in response to increased

AVSTM demands using computational modeling as well as with a paired-word repetition paradigm. In this experiment, we administered a similar word-pair repetition task to determine the consequences of increasing AVSTM demands on the quality of MMB's error corpora and to evaluate the generalizability of the continuum hypothesis to lexical repetition disorders.

Method

The paired word repetition task was carried out 1 month following the single-word repetition task, using the same 240 items. Words were arranged in pairs within each of the four groups of 60 items: High frequency/high imageability, high frequency/low imageability, low frequency/high imageability, and low frequency/low imageability. Pairing of words within groups was random. Word pairs were presented from an audiotape to avoid lip cues. The second word in a pair was presented immediately following presentation of the first word. MMB was encouraged to respond in the same serial order immediately following presentation of the second word in a pair. Responses were tape-recorded and scored subsequently by one of the experimenters and an assistant.

Analyses focused first on general error profile regardless of an item's position in a pair. Potential effects of serial position were then examined. The effects of target length, frequency, and imageability were examined separately for words at Position 1 and Position 2. Individual formal error → target relationships were then examined irrespective of serial position to identify the influence of length, frequency, and grammatical class on the production of formal paraphasias. In a separate analysis, only errors in which MMB attempted responses to both items in a pair were analyzed to assess the influence of increasing AVSTM demands on the quality of her error corpora.

Results and Discussion

MMB repeated correctly .51 of the total 240 words. Her decreased accuracy compared to performance on the same words in the single-word repetition experiment is likely attributable to increased demands on AVSTM associated with the requirement to retain word pairs. As in Experiment 2, MMB's most common error was nonresponse (.45 of total trials). As with both previous single-word repetition experiments (see Background Investigation and Experiment 1), formal paraphasias dominated her response-based error corpora (.29). There was a striking increase in the proportion of MMB's semantic paraphasias (.22 of response-based errors compared to only 1 semantic error in Experiment 1). Phonemic paraphasias accounted for .15 of response-based errors. Other errors included derivatives (e.g., interest → interesting) and unrelated lexical (e.g., equipment → community). None of MMB's errors were non-target-related neologisms, as was the case in the single-word repetition experiment. MMB's high proportion of lexical compared to phonemic paraphasias replicates the ''lexical bias'' observed in the single-word repetition experiment.

Serial Position Effects

As expected, MMB's responses were significantly more accurate on words at position 1 (.61) than on words at position 2 (.41) [$\chi^2(1) = 9.60$, $p < .002$]. MMB's limited ability to retain the second word of a pair is consistent with the reduction of recency in her AVSTM digit span performance.

Position 1. MMB's response-based errors at Position 1 were primarily formal, phonemic, and unrelated lexical paraphasias. Figure 3 shows the proportions of these errors at Position 1 under high- and low-frequency and -imageability conditions. Analysis of variables potentially affecting MMB's formal errors failed to replicate the frequency effect found in the single-word repetition experiment. Although MMB did produce more formal paraphasias on low-frequency words (.59) than high-frequency words (.42), the difference was not significant ($p = .05$). As in the single-

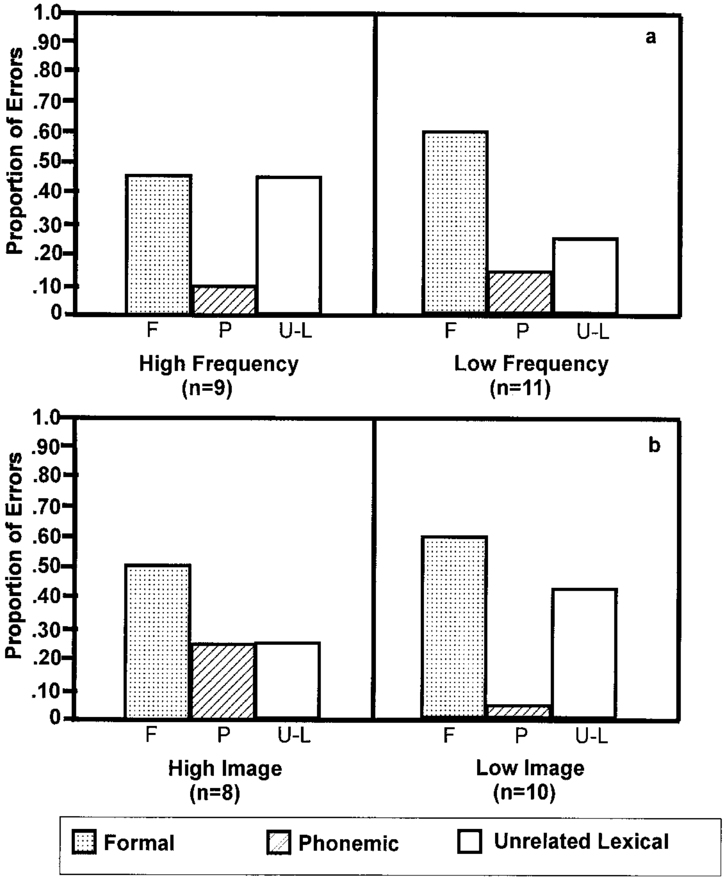

FIG. 3. Patterns of MMB's repetition errors at Position 1 as a function of target word's (a) frequency and (b) imageability.

word repetition experiment, there was also no effect on formal errors of length (one syllable = .47, two syllables = .42, three syllables = .11) or imageability (.47 high imageability, .53 low imageability) ($p = .05$).

Position 2. Figure 4 shows the distribution of response-based errors at Position 2 under conditions of high and low frequency and imageability. The most striking finding of the word-pair repetition experiment was the emergence of semantic paraphasias in MMB's error corpora at Position 2, as predicted by the fully interactive activation hypothesis. MMB produced only one semantic error in the single-word repetition experiment and did not produce any semantic paraphasias at Position 1 of the paired-word experiment. At Position 2 of the paired word experiment, .43 of MMB's response-based errors were semantic paraphasias. The remainder of MMB's errors at Position 2 were phonemic (.29) and formal (.28) paraphasias.

Target imageability had a dramatic influence on the occurrence of semantic errors at Position 2. MMB produced semantic paraphasias on .25 of high-imageability targets compared to only .05 of low-imageability targets, and this difference was significant [$\chi^2(1) = 9.41$, $p < .002$]. Thus, as was the case with the patient described by Martin et al. (1996), MMB's semantic paraphasias are produced under conditions of increased AVSTM demand and greater word imageability. Frequency also had an effect on the occurrence of semantic errors at Position 2 (semantic errors on .22 of high-frequency targets compared to .08 of low-frequency targets) [$\chi^2(1) = 4.18$, $p < .041$].

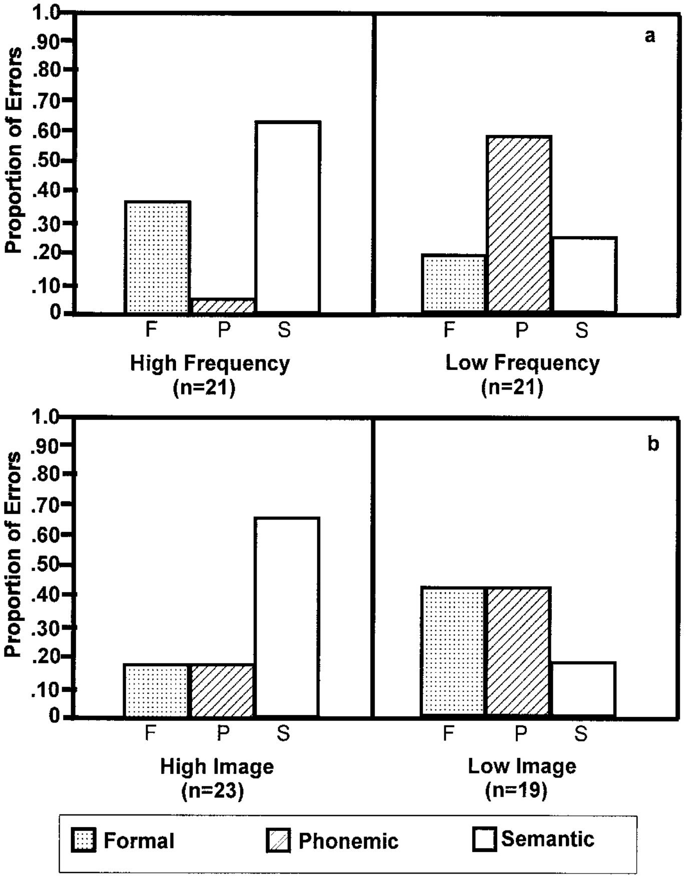

FIG. 4. Patterns of MMB's repetition errors at Position 2 as a function of target word's (a) frequency and (b) imageability.

Neither frequency nor imageability influenced the occurrence of formal errors at Position 2. Not surprisingly, frequency affected the occurrence of phonemic errors at Position 2, with a significantly greater proportion of phonemic errors on low-frequency targets (.20) compared to high-frequency targets (.00) [$\chi^2(1) = 13.33$, $p < .001$].

Formal Error → Target Pairs

Examination of individual formal error → target relationships at either position revealed similar roles of frequency, length, and grammatical class on the production of formal paraphasias found in the single-word repetition experiment. As in the single-word repetition experiment, formal errors were of higher frequency than their targets in more than half of cases (higher frequency in 0.65 of cases, lower frequency in 0.35 of cases, and equal in 0.06 of cases). The tendency for targets to be replaced by words of higher frequency approached significance (Sign test: $N = 16$, $z = 1.81$, $p < .071$, two-tailed).

As in the single-word repetition experiment, the greatest agreement in phonology between formal errors and target was at initial consonant (.68 of formal errors). Target length again did not seem to play a role in the generation of MMB's formal paraphasias, as was the case in repetition of single words. MMB's formal errors were longer than their targets in 0.50 of cases, equal in 0.25 of cases, and shorter in 0.25 of cases. A length analysis conducted on MMB's formal paraphasias indicated that the tendency for MMB's formal errors to be longer than targets was not significant (Sign test: $N = 16$, $z = 1.16$, $p > .248$, two-tailed).

Finally, MMB's formal errors were again constrained by target grammatical class (1.0 of her formal paraphasias remained within the target's grammatical class), further indicating semantic involvement in her production of formal paraphasias.

Word-Pair Effects

As mentioned, instructions to repeat word pairs likely placed increased demands on MMB's AVSTM relative to single-word repetition. However, the only trials for which we can be *certain* of increased AVSTM demands are those to which MMB offered a response to both words in a pair. In this section only trials in which MMB attempted responses to both items in a pair were analyzed (0.53) to assess the influence of increasing AVSTM demands on the quality of her error corpora. MMB repeated correctly and in serial order only .28 of the 120 total word pairs. On .25 of total trials, MMB generated responses to targets at both positions, but produced at least one error. The results of these trials are reported here. At Position 1, MMB's most common error was the formal paraphasia (0.18), followed by the phonemic and derivative errors (0.07 each). At Position 2, MMB's most common error was the semantic paraphasia (0.23), indicating that her high proportion of semantic errors at the second position are attributable to increased AVSTM demands. Formal errors accounted for 0.12 of errors at Position 2.

GENERAL DISCUSSION

We have presented the case of MMB, a patient with conduction aphasia characterized by severely impaired repetition and relative sparing of auditory comprehension and naming. MMB produced a high rate of formal paraphasias in repetition. Such sound-related whole-word substitutions are rare in aphasia. In fact, Ellis (1985) suggested that formal paraphasias were not anticipated in aphasia because they implied a higher degree of language functioning than would be expected in aphasic patients. Indeed, the majority of conduction aphasics (Dubois, Hécaen, Angelergues, de Chatelier, & Marcie, 1964; Goodglass & Kaplan, 1972; Kohn, 1984), and patients with phonologically-based STM impairment (Vallar & Shallice, 1990), produce far more phonemic than formal paraphasias.

Early theories of formal errors characterized them as sublexically generated errors that happen by chance to sound like real words (Butterworth, 1979; Lecours, Deloche, & Lhermitte, 1973). However, several case studies have since reported patients who produce formal errors at rates that far exceed chance expectations (Best, 1996; Blanken, 1990, 1998; Martin & Saffran, 1992). MMB's repetition profile provides another example of such a case because she generated formal errors at more than double the rate of phonemic errors in three repetition tasks.

The nature and origin of formal errors in normal language has been examined in spontaneous slips-of-the-tongue of non-brain-damaged subjects (Aitchison & Straf, 1982; Fay & Cutler, 1977). These studies reported that phonological overlap of formal errors and targets was greatest at initial consonant. Fay and Cutler suggested that the overlap of initial consonant in targets and malapropisms pointed to the existence of a lexicon arranged according to phonological features of words. Fay and Cutler (1977) concluded that malapropisms in normal spontaneous speech were errors of lexical selection. The parallel claim in repetition would be that formal paraphasias are errors of lexical retrieval (i.e., errors in accessing words in a phonologically based lexicon). Can MMB's formal paraphasias in repetition be the result of errors in lexical retrieval? This hypothesis was tested in Experiment 4. MMB placed in the Average range for her age cohort on the PPVT, and at ceiling on the Lexical Comprehension Test, which includes phonological and semantic distractors. Thus, her lexical knowledge is not impaired. In terms of access to lexical knowledge, examining the subgroup of words presented both for repetition and lexical decision, 0.20 of MMB's formal paraphasias were generated on targets she was unable to identify as words. Errors in lexical retrieval, then, can potentially explain a small portion of MMB's formal paraphasias.

As for the majority of MMB's formal paraphasias, results of repetition tests favor the fully interactive activation account over phonological interactive encoding account. Results did not support the phonological interactive encoding hypothesis because target length did not influence the occurrence of formal errors in either repetition experiment. Similarly, the length of MMB's formal errors relative to targets did not follow any specific pattern across the two repetition experiments: Formal paraphasias tended to be the same length as targets in the single-word experiment and longer than targets in the paired-word experiment, and neither trend approached significance. Finally, more generally, the finding that MMB shows only mildly impaired naming and reading is not consistent with the theory that her formal paraphasias result from damage to speech production systems.

Results did not entirely support the fully interactive activation hypothesis either because MMB did not show imageability effects in formal errors (discussed further below). However, support for the fully interactive activation hypothesis was found in several areas. Before examining the degree of fit of MMB's data with the fully interactive account, it is helpful to outline Dell's input language model.

Figure 5 illustrates Martin and Saffran's (1992) adaptation of Dell's language production model to input processes to account for comprehension/repetition. Phonological nodes primed by auditory input spread activation to the lexical target (Lt), to phonologically related lexical nodes (Lp), and, to a lesser extent, to phonologically related lexical nodes which happen to be related to the target semantically (Lsp). Phonological nodes begin to decay. Activated lexical nodes then prime corresponding semantic nodes through feedforward processes and decaying phonological nodes through feedback processes. These activated semantic and phonological nodes begin to decay. Decaying lexical nodes then receive ''second-order priming'' from primed semantic nodes. At the same time, semantically related lexical nodes (Ls) are activated by feedback from primed semantic nodes, which is called ''third-order priming.'' Finally, the lexical node with the most priming is selected and transmitted to output processes. Importantly, the fully interactive activation model assumes that semantic errors in comprehension/repetition are less likely under normal conditions than formal errors because Ls are primed relatively late in the lexical selection process.

The fully interactive activation hypothesis holds that the inability to sustain activation of phonologically primed lexical nodes over time is a crucial variable in the generation of formal errors. MMB has a restricted AVSTM capacity (two to three items). Moreover, the significant decline in her performance in the delay conditions of the phoneme discrimination task indicates that input phonological units are subject to a rapid decay over time. As a result of the increased rate of decay of lexical nodes, the lexical target relinquishes its initial advantage over phonologically related lexical competitors before the return of feedback from semantic nodes. The word eventually selected for output is the one with the highest resting activation rate, typically the

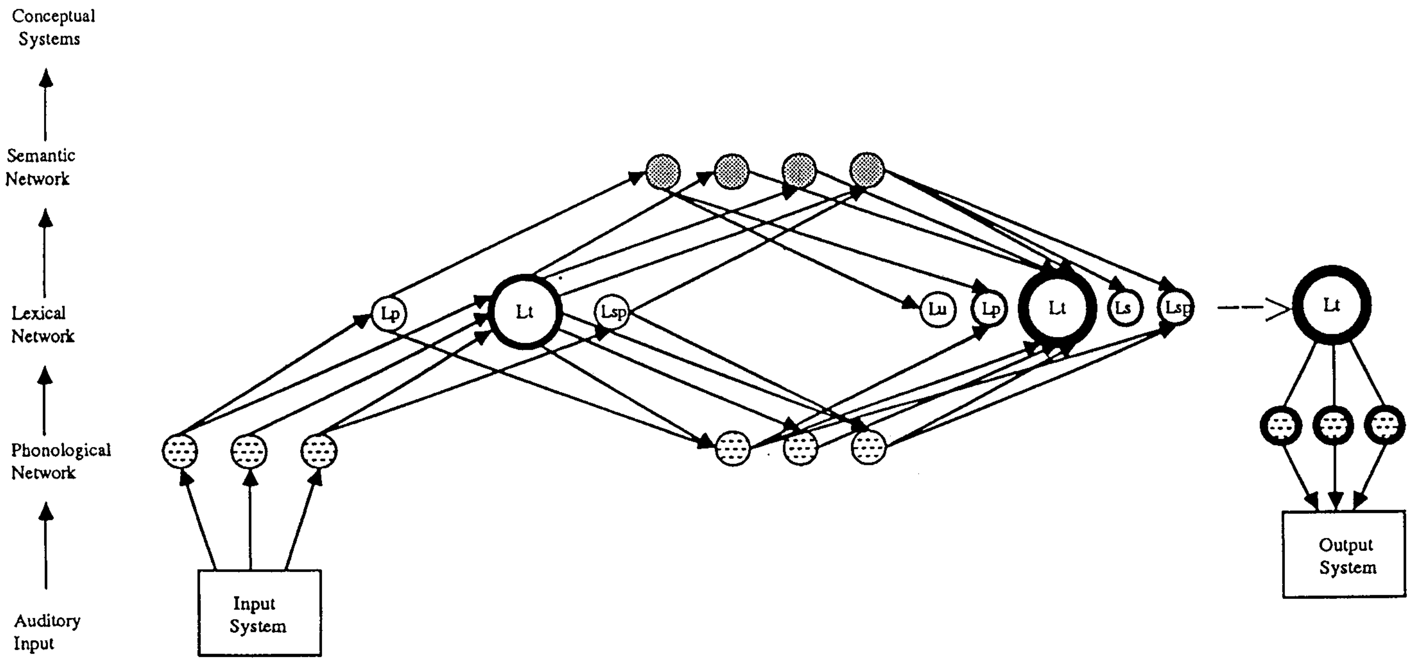

FIG. 5. Martin et al. adaptation of Dell's language production model to input processes to account for comprehension/repetition. Reproduced from Martin, Dell, Saffran, and Schwartz (1994) with permission.

most frequent word, among phonologically related lexical competitors. MMB produced significantly more formal paraphasias on low-frequency than high-frequency targets in Experiment 1 (the same trend was found in Experiment 6, but failed to reach significance). Also, MMB's formal word substitutions tended to be of higher frequency than targets in both Experiments 1 and 6.

The incidence of lexically based repetition errors in aphasia would be expected to be considerably greater if a restricted AVSTM span, combined with a rapid decay of linguistic units over time, provided sufficient cause. However, a basic assumption of the fully interactive activation model is that lexical errors in repetition require adequate priming of all nodes in the phonological-lexical-semantic network. For example, according to the interactive activation model, an aphasic patient with impaired AVSTM span, and an accelerated rate of decay of linguistic units over time, would nonetheless be unlikely to produce a high proportion of formal errors in repetition if initial phonetic processing was also significantly impaired because such impairment would limit the opportunity for phonologically related lexical competitors to be primed. Thus, the rarity of formal errors in aphasia is a result of the requirement of intact initial phonetic processing concomitant with a restricted AVSTM span and a pathologically accelerated decay of nodal units over time.

The fully interactive activation hypothesis also assumes that activated lexical nodes spread to, and prime, semantic nodes (even when semantic processing is not strictly necessary) and thus predicts that formal errors will be constrained by the target's grammatical class. MMB's formal paraphasias were in line with this prediction in both experiments.

Finally, the fully interactive account predicts a higher proportion of semantic paraphasias in repetition in response to increased AVSTM demands. In repetition, information flow across the nodal network is assumed to proceed from phonological to lexical to semantic levels of representation. The consequence of this ordering of information flow is that phonological nodes are most vulnerable to decay, while semantic nodes are less susceptible, because they are exposed to a shorter period of time passage in the process of repeating a word. In paired-word repetition, the availability of semantic nodes relative to phonological nodes should be greatest at Position 2 because time until word production will be longest. Therefore, the interactive activation theory predicts an increase in the proportion of semantic relative to formal paraphasias at Position 2 (Martin et al., 1996). Data from MMB supported this notion. There was a significant increase in the proportion of MMB's semantic paraphasias at Position 2 of the paired-word experiment compared to Position 1 and compared to the single-word repetition experiment.

The interactive activation account further predicts that semantic paraphasias at Position 2 will cluster around high-imageability targets. The basis for this prediction is that concrete words are believed to have ''richer'' representations than abstract words, sharing more semantic features with each other and therefore having more semantic competitors than abstract words. Thus, a highly imageable word at Position 2 further shifts the availability of semantic nodes relative to phonological nodes in repetition. This prediction was confirmed. Imageability strongly influenced the occurrence of MMB's semantic errors at Position 2.

As mentioned, the fully interactive activation account's prediction of imageability effects on formal errors could not be confirmed in the present research. There are at least two potential explanations for the failure to find an imageability effect in the generation of MMB's formal errors. One possible explanation is that, contrary to the assumption of the Dell input language model, lexical nodes do not spread automatically to, and prime, semantic nodes during the process of word repetition. Another potential interpretation is that lexical nodes do prime semantic nodes during repetition but that the relative sparing of MMB's semantic processing from auditory input served to constrain the accuracy of reverberating semantic feedback. Several findings render the former interpretation unlikely and lead us to favor the latter explanation. First, the accuracy of MMB's repetition was influenced by target imageability, with greater success on words of high imageability. Second, MMB's ability to repeat words she could not define was significantly poorer than her general repetition. These findings suggest that lexical nodes do receive feedback from semantic nodes in the process of repetition. Thus, it appears that MMB's relatively retained semantic processing enabled priming of corresponding semantic nodes and feedback to lexical nodes, decreasing the influence of word imageability on the generation of her formal errors. For MMB, then, word imageability seems only to influence the quality of repetition errors when combined with increased AVSTM demands (as in the paired word experiment). Future research will be needed to clarify the influence of word imageability on the production of formal errors.

The primary focus of the present research concerned an examination of the nature of impairments underlying MMB's formal errors in repetition. However, results from MMB may have more general implications for models of language production concerning the issue of input modality. Many cases of deep dyslexia have been reported in which repetition is largely intact (Coltheart, 1980). These patients are sometimes assumed to have access to an unimpaired auditory–phonological conversion route, enabling repetition (Morton & Patterson, 1980). The existence of these cases poses a challenge to interactive models of language production, which assume that a single, amodal language processor serves production of language. Such cases provide support for models maintaining modality-specific input routes subserving reading and repetition, such as Morton and Patterson's (1980) well-known logogen system.

MMB demonstrated modality effects across a range of tasks. Most notably, MMB's reading was superior to her repetition, and she did not produce formal errors in reading. On first pass, this modality effect would seem to support production models such as logogen. However, MMB's reading was also significantly impaired. Moreover, as with repetition, MMB's reading was influenced primarily by lexical variables (item regularity and frequency in the case of reading). Also, as with repetition, MMB's production from the visual input modality tended to preserve item lexicality. The consistent effects of stimulus variables on performance across modality are predicted by interactive models and do not support a conclusion of separate routes for repeating and reading. It is noteworthy that the patients described by Martin et al. (1992) and Blanken (1998) showed a similar continuity of effect of stimulus variable across modality. Each patient's reading was impaired—albeit less so than their repetition—and was influenced by the same variables affecting repetition [imageability in the case of Martin et al.'s (1992) patient; length in the case of Blanken's (1998) patient].

The issue of input modality in production is likely to be best served by engaging deep dyslexic and deep dysphasic patients in reading and repetition tasks involving the same stimuli (separated by an appropriate time interval) and presenting input for repetition via audiotape to avoid lip cues. Even in those patients demonstrating clear modality effects, it may be informative to compare the effects of stimulus variables across reading and repeating. For example, it was only in the course of examining their deep dyslexic patient's AVSTM that Nolan and Caramazza (1982) discovered a repetition impairment paralleling his reading disorder. Despite modality effects, the accuracy of the patient's repetition was influenced primarily by length, lexicality, and abstractness—the same variables that affected his reading. The importance of input modality on qualitative aspects of language production awaits future research.

APPENDIX A

MMB’s Formal Repetition Errors

Prison → Present
Fact → Fat
Center → Sender
Student → Steward
Trade → Tried
Hair → Here
Winter → Window
Truck → Table
Cane → Cage
Insolence → Inside
Truth → Truce
Joy → Joke
Abdomen → Abysmal
Instance → Instinct
Hindrance → Entrance
Mange → Engine
Profession → Perfection
Landscape → Landslide
Charlatan → Charlettown
Lint → Link
Position → Possession
Keg → Khaki
Nonsense → Nuisance
Blandness → Blindness
Hour → Arrow
Obsession → Emission
Reptile → Rectangle
Franchise → Friendship
Deed → Deep
Chief → Cheap
Sheen → Shave
Gist → Justice
Lie → Law
Fate → Fit
Shotgun → Shut-up
Headlight → Highlight
Blandness → Blindness
Pudding → Plastic
Node → Noble
Sea → Seed
Grout → Grouch
Amount → Mountain
Kilt → Kind
Instance → Instinct
Shotgun → Sharp
Satire → Saber
Malady → Marmalade
Insolence → Insolvent

APPENDIX B

MMB’s Semantic Repetition Errors

Professor → Teacher
Equipment → Mechanic
Opinion → Important
Hurricane → Earthquake
Diamond → Onyx
Palace → Castle
Revolver → Shotgun
Honor → Pride
Money → Invest
Letter → Suitcase
Factory → Arena
Bungalow → House
Dress → Clothes

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