

On the Nature of the Phonological Output Planning Processes Involved in Verbal Rehearsal: Evidence from Aphasia

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This paper describes the performance of an aphasic patient, R.W., in producing the sounds of words and in verbal rehearsal. R.W. showed evidence of retained abilities to access aspects of the forms of spoken words but made numerous phonemic paraphasias in single word production tasks. He did not show features of dysarthria or apraxia of speech. This pattern indicates that his deficit affected a process that plans the phonological forms of spoken words. R.W.'s performances in short-term memory and metalinguistic tasks involving single words were consistent with impaired rehearsal functions. The pattern of results indicates that rehearsal requires planning of the phonological forms of spoken items and suggests that activating entries in the phonological output lexicon is not adequate to permit rehearsal to proceed normally. © 1995 Academic Press, Inc.

Rehearsal processes are widely thought to play an important role in the performance of auditory-verbal short-term memory tasks, such as span and delayed recall, and in certain metalinguistic tasks involving single words, such as rhyme judgments. The mechanisms underlying rehearsal have been the subject of a number of recent investigations. This paper presents new data from the performance of an aphasic patient regarding the nature of the mechanism that underlies verbal rehearsal functions.

Baddeley and his colleagues (Baddeley 1966; Baddeley, Thomson, & Buchanan, 1975) have argued that one mechanism underlying rehearsal involves subvocal articulation. Their argument was based upon several findings.

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The first of these findings is the effects of word length on performance in span tasks in normal subjects. Baddeley et al. (1975) reported an advantage for monosyllabic words over five-syllable words on number of lists recalled in span tasks. They repeated these experiments with words of different articulatory durations controlled for syllable number and number of phonemes and reported that the word length effect continued to be found for these sets of stimuli in auditory span tasks and in visual span tasks in which the subjects were instructed "to remember the lists by repeating the words to themselves" (page 581). Baddeley and co-workers argued that these effects, and the correlation of span with articulatory and reading rates, showed that "short term memory is a time-based system" (p. 581), in which "a subject can recall as many words as he can read in 1.6 sec or can articulate in 1.3 sec" (p. 581). Rehearsal processes are thought to be responsible (at least in part) for this relationship.

Further support for the role of articulatory based mechanisms in rehearsal comes from the disappearance of both the visual and auditory word length effects under conditions of articulatory suppression, provided that articulatory suppression takes place both throughout list presentation and recall (Baddeley, Lewis, & Vallar, 1984; Baddeley et al., 1975). Baddeley et al. argued that articulatory suppression interfered with an articulatory-based rehearsal mechanism that is responsible for word length effects in both auditory and visual span (Baddeley & Lewis, 1984; Baddeley, 1986). Similar results to those of Baddeley et al. (1984) were reported by Martin (1987) under conditions in which subjects were instructed to rehearse visually presented words. The phonological similarity effects are thought to reflect the operation of the Phonological Store and so should be less affected by articulatory suppression (Baddeley et al., 1984). Though suppression does not abolish the effect of phonological similarity for auditorily presented material (Murray, 1968), it does abolish the effect of phonological similarity on visual span. This is claimed to occur because whereas spoken material has direct access to the phonological store, suppression interferes with visual material entering the Phonological Store.

Rehearsal is also thought to be involved in several metalinguistic tasks involving single word processing. Besner, Davies, and Daniels (1981) have demonstrated that visual rhyme judgments are impaired by concurrent articulation in normal subjects, while visual homophone judgments are intact (or, at least, less clearly impaired). These authors have argued that this pattern indicates that an articulatory-based rehearsal process is involved in visual rhyme but not visual homophone judgments.

Recently, data from patients with acquired brain lesions have reopened discussion of the nature of the mechanisms underlying rehearsal. Patients with severe disturbances of articulation ("dysarthria") have been shown to have normal memory spans and normal effects of both phonological

similarity and word length in span tasks (Baddeley & Wilson, 1985; Nebes, 1975; Levine, Calvanio, & Popovics, 1982; Vallar & Cappa, 1987). Similar data have been reported for children with abnormal speech due to cerebral palsy (Bishop & Robson, 1989). These findings suggest that severe disturbances of articulation per se do not eliminate word length effects and cast doubt on the role of articulation itself in rehearsal processes in span. On the other hand, patients with higher-level articulatory disturbances (patients with "apraxia of speech"), in whom articulation disturbances may be attributable to disturbances of articulatory implementation that arise at a higher level of speech planning than those in dysarthria, rather than an inability to produce such gestures from intact plans, have been shown to lose word length effects in both auditory and visual span tasks (Rochon, Caplan, & Waters, 1991; Waters, Rochon, & Caplan, 1992). Patients with dysarthria have not been tested for their abilities to make visual rhyme and homophone judgments, but patients with apraxia of speech have been shown to show the same pattern as normals under conditions of articulatory suppression on these tasks—impaired rhyme but not homophone judgments (Waters et al., 1992). These findings suggest that rehearsal mechanisms make use of speech planning processes that specify articulatory gestures, but do not require articulatory gestures themselves.

The argument that rehearsal involves a more abstract level of speech production than actual articulation receives further support from additional data regarding the word length effect in normals. Caplan, Rochon, and Waters (1992) replicated Baddeley et al.'s finding of an effect of word length on auditory and visual span when the stimuli consisted of words that differed in terms of the number of syllables, but then showed that, *contra* Baddeley et al. (1975), the effects of word length were eliminated when the words in the span task were matched for the number of syllables and phonemes but differed with respect to their duration and/or the complexity of their articulatory gestures. Caplan and Waters (in press) partially replicated and extended these findings. These results are consistent with those derived from the neuropsychological cases described above and suggest that it is some process associated with planning the phonological structure of a word and not features of its actual articulation that determines the magnitude of the word length effect in span tasks. The authors argued that this implies that this process is involved in rehearsal.

To explore the question of the speech processes that are involved in rehearsal further, we must refer to a model of the stages of the word sound production process. We can then attempt to identify which processes that are specified in this model are involved in rehearsal.

Most models of speech production postulate that the sound of a word is produced in several steps (see Levelt, 1989, Chapter 9, for discussion). Though details vary, these models tend to share the assumption that

speakers first access a partial phonological representation of a word from a concept, and then perform a number of operations on that representation to render it into a form that is suitable for programming the articulators. We shall briefly review the arguments that support this set of models and that provide data on which to base accounts of what might be represented at the various stages of speech output planning.

First, several everyday observations and considerations suggest that the phonological form of a word that is accessed from semantics does not constitute a complete specification of the articulatory values that are produced when the word is actually uttered. Words can be uttered with various intonation contours, at different loudness levels, in whispered form (i.e., without any voicing), and in many other ways that lead to very different articulatory gestures being associated with their constituent sounds. Though we do not know the storage capacity of the human brain, it is unlikely that all these articulatory forms are permanently stored for each word in a speaker's vocabulary. What is much more likely is that a speaker accesses a standard (or "canonical" or "citation") form of a word, which is then modified as a function of speech loudness, speed, etc. Co-articulation phenomena (the effect of phonetic context on the articulatory features of a phonemic segment, e.g., the rounding of /p/ in *pool* but not in *pit*) also suggest that accessed phonological representations are underspecified for articulatory details.

The above considerations provide intuitive support for a distinction between the phonological representations that are accessed when a word is spoken and the specification of articulatory values associated with those representations. In addition to realizing phonological representations in a variety of articulatory ways, speakers also systematically change phonological features of the sounds of words as a function of their phonological environment when they produce the sounds of words. For instance, in English, all unstressed vowels are reduced to a common short vowel, schwa (/ə/). Thus, despite the differences in their orthographic realizations, the vowels in the second syllables of *anecdote*, *matador*, and *Canada*, sound almost the same and all are transcribed phonologically as /ə/. However, the spelling of these words is actually a guide to true differences among these vowels, which can be seen in several phenomena related to word formation (e.g., the second vowel in the word *Canada* is related to the second vowel in the word *Canadian*). Other instances of changes in underlying phonological features include the diphthongization of tense vowels in English (that is, tense vowels are followed by glides: *cry*, *bay*, *bow*, *blue*) and a process known as "vowel shift" that affects the features [high] and [low] in tense diphthongized vowels (Chomsky & Halle, 1968). Phonologists have argued that these phenomena can be described by postulating lexical phonological segmental repre-

sentations that are underspecified in certain respects and whose final phonological values are affected by syllabification, stress assignment, and certain morphological processes (see Pesetsky, 1979; Mohanan, 1982; Grignon, 1984; and Halle & Mohanan, 1985 for discussion).¹ Beland, Caplan and Nespoulous (1990) have argued that the phonological representations that are accessed in the mental dictionary for oral production (the so-called "phonological output lexicon") contain such underspecified phonological information.

The notion that speakers access a phonological representation that is transformed during the process of planning the articulatory gestures associated with a word also receives support from experimental and behavioral observations. The "tip-of-the-tongue" phenomenon (Brown and McNeill, 1966) and features of malapropisms (Fay and Cutler, 1977) indicate that a word's onset, the number of syllables in the word, which syllable is stressed, and sometimes the final segment of the word, can be accessed separately from other phonological features.

These data encourage us to conceive of lexical phonological activation as consisting of two cognitively separate processes. The first process—which we will call "lexical phonological access"—links the semantic and syntactic representation of a word to its underlying phonological representation. Lexical phonological access must make use of an associative mechanism, since word forms are not accessible from word meanings on a content-addressable basis. The second process—which we will call "lexical phonological planning"—adds and changes phonological features in this representation. The process of lexical phonological planning can be implemented as a production system.

This division of lexical phonological activation into two stages bears some resemblance to models developed in other branches of cognitive psychology, especially cognitive neuropsychology, that distinguish between a phonological output lexicon and a "response buffer," whose role is to maintain sequences of phonemes in memory while articulation is being planned (Caramazza, Miceli, & Villa, 1986). Models that contain the two stages described above do not necessarily specify entities that map in a one-to-one fashion onto the components specified in models containing a phonological output lexicon and a response buffer, however, since the representations and operations specified in different models differ. However, in broad terms, one can conceive of the lexical phonological access and planning stages in models of the sort we have been discussing as corresponding to the activation of items in the phonological

¹ Note that the surface phonological values that are established by these processes are still subject to changes at the articulatory level due to loudness, whispering, co-articulation, etc.

output lexicon and the response buffer in models that specify these two functional components.²

One question that can be asked about rehearsal is whether accessing a lexical phonological representation is sufficient for rehearsal to occur, or whether the entire set of processes involved in specifying the phonological content of a word is required for rehearsal to proceed. This question can be rephrased in the terminology used in some neuropsychological

² A brief description of the major differences between models is as follows. In some models (e.g., Beland et al., 1990), the accessed phonological representation, though underspecified, completely determines the final phonological content of the word (though not its complete articulatory nature, as discussed above). In these models, the phonological changes effected by the phonological planning process are completely due to the action of language-universal and language-specific phonological rules upon the underspecified underlying phonological representations that are accessed from a word's semantics. In these models, the phonological representations that are initially accessed from semantics could be considered to be entries in a phonological output lexicon. However, they are different from the representations that most neuropsychologists appear to have in mind when they discuss the phonological output lexicon, since they are underspecified phonologically. In other models, the phonological representation that is first accessed from lexical semantics is not the entirety of the entry for the word in the phonological output lexicon. For instance, Levelt (1989) specifies two major stages of lexical access—one in which the conceptual and syntactic features of a word are activated (the word's "lemma") and a second stage at which the phonological features of a word are activated (the word's "lexeme"). This second stage is in turn divided into two: in a first stage of word sound production ("morphological-metrical spellout"), a word's morphological and syllabic structure are activated and, at a second stage ("segmental spellout"), information regarding the segments found in each word is added. For instance, the concept (*person who is at large from the law*) might activate the features (singular noun) and (3 syllables) at the morphological-metrical spellout stage and the phonological segments /fʃudzitiv/ at the segmental spellout stage. The morphological-metrical spellout stage does not provide enough information to individuate lexical entries (there are many nouns with three syllables in English) and therefore cannot constitute the entirety of the information in the phonological output lexicon. The combination of the first and second stages in this model does together provide enough information for lexical phonological individuation. Though the process of activating entries in the phonological output lexicon is only completed when these two stages have been successfully negotiated, we may think of the morphological-metrical spellout stage as the process of phonological lexical access and the segmental spellout stage as the process of phonological planning in Levelt's model. In this case, the phonological planning stage must also be a partially associative process. The notion of a phonological output lexicon that has developed in the neuropsychological literature maintains that lexical phonological representations are fully specified with respect to their phonemic segments. Most of these models do not hold that the activation of items in the phonological output lexicon takes place in stages. Activating entries in the phonological output lexicon corresponds to the lexical phonological access stage. The processing that corresponds to the stage of phonological planning takes place in what is called a "response buffer." What happens in the response buffer appears to be the preparation of these phonemes for articulation; i.e., the specification of actual articulatory gestures, which requires consulting sequences of phonemes. Therefore, the processing in the response buffer differs from the planning described above in both a Beland-type and a Levelt-type model.

models as the question of whether accessing a phonological representation in the phonological output lexicon is sufficient for rehearsal to occur.

The present study investigates the question of what aspects of phonological output processing are needed for rehearsal to proceed by examining the rehearsal abilities of a patient with a speech production impairment called "conduction aphasia" or, more recently, "reproduction conduction aphasia" (Shallice & Warrington, 1977). Patients with reproduction conduction aphasia have a disturbance in speech production that affects the production of single spoken words. Their speech is characterized by numerous phonemic paraphasias (omissions, substitutions and misorderings of the phonemes of a word), but they give no signs of misarticulation, of either the more peripheral or more central sorts that are associated with dysarthria or apraxia of speech. The functional locus of the speech production deficit in patients with reproduction conduction aphasia is thought to be somewhere between the activation of word forms in a phonological output lexicon and the execution of articulatory gestures. The deficit probably varies from patient to patient, since there are individual differences among patients with respect to the exact frequency of the different types of phonemic errors they make; the relative rate of error production in picture naming, repetition, and oral reading tasks; the relative rate of error production for words and non-words; and the ability of patients to indicate that they are aware of aspects of the phonological forms of words that they cannot produce in picture naming tasks (the presence of the tip-of-the-tongue state). Some of these patients appear to access lexical phonological representations in the phonological output lexicon, while others appear not to do so (see Caplan and Waters, 1992, and Caplan, 1992, for discussion).

The data presented at the outset of this paper indicate that rehearsal involves speech planning processes that specify the articulatory gestures associated with phonological segments, but does not require articulatory gestures to take place normally. The study of patients with reproduction conduction aphasia allows us to further characterize the speech planning processes that are required for rehearsal. One possibility is that the ability to access a phonological representation is sufficient for rehearsal to proceed. If so, those patients with reproduction conduction aphasia who show retained ability to access lexical phonological forms should retain the ability to rehearse. Alternatively, the ability to access a phonological representation may not be sufficient for rehearsal to proceed; successful planning of the phonological form of a word may be needed for rehearsal to proceed. If this is the case, patients with reproduction conduction aphasia who show retained ability to access lexical phonological forms but impaired phonological planning should not rehearse normally.

In this paper, a patient is presented whose output disturbance appears to affect phonological planning processes that arise after at least many

aspects of word form have been activated in the phonological output lexicon. The patient fails to show normal performance on tasks that are thought to require rehearsal. The conclusion that is drawn is that rehearsal requires some aspect of output phonological planning.

CASE PRESENTATION

R.W. was a 62-year-old right-handed male who had a small, non-hemorrhagic stroke in May, 1991. He was admitted to a rehabilitation hospital on June 6, 1991. MR imaging revealed a small left temporal infarction (see Fig. 1). R.W. was a college graduate and had previously worked as an executive for a research corporation.

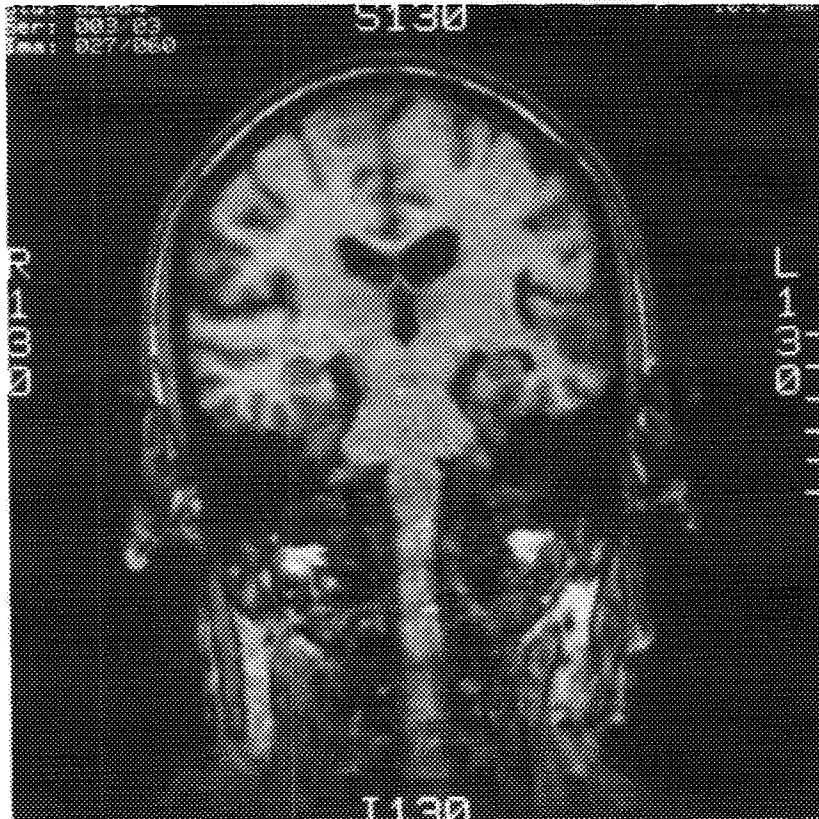


FIG. 1. T₁ weighted coronal MR image for patient R.W., demonstrating an area of necrosis in the left temporal lobe.

TABLE 1
R.W.'s performance on the *Boston Diagnostic Aphasia Examination*

Test	June, 1991	July, 1991
Auditory comprehension		
Word discrimination	42/72	58/72
Body part identification	12/18	14/18
Commands	9/15	9/15
Complex ideational material	10/12	10/12
Oral expression		
Automatized sequences	7/8	7/8
Word repetition	2/10	5/10
Phrase repetition	2/16	0/16
Word reading	9/30	10/30
Responsive naming	24/30	24/30
Animal naming	12/1 min	15/1 min
Oral sentence reading	3/10	
Understanding written language		
Symbol and word recognition	10/10	10/10
Word recognition	7/8	7/8
Reading sentences and paragraphs	9/10	9/10
Writing		
Mechanics of writing	5/5	5/5
Spelling to dictation	1/10	9/10
Boston naming test	22/60	47/60

Language Evaluation

B.D.A.E. R.W. was tested on parts of the Boston Diagnostic Aphasia Examination (B.D.A.E.) in June, 1991, upon admission to the rehabilitation hospital, and again upon discharge in August, 1991. His performance is shown in Table 1. His output was described as fluent. He was considered to have mild-to-moderate impairments in auditory comprehension, which improved somewhat over that period of time. Written sentence comprehension was considered to be better than auditory sentence comprehension. Repetition was severely impaired at the word and sentence levels.

B.N.T. R.W. was tested on the Boston Naming Test (B.N.T.) on several occasions. Responses were tape-recorded and transcribed in IPA by a trained speech-language pathologist. On June 24, 1991, he scored only 22/60; his errors consisted of phonemic errors, false starts, and occasional omissions. The BNT was repeated on July 25, 1991 and August 8, 1991, and R.W. scored 47/60 and 46/60 on those two occasions. The types of errors he made were identical to those made when he was tested in June. Table 2 shows examples of the errors he made in the BNT on the first test session. These errors retain many phonological features of

TABLE 2
Examples of phonological errors made by R.W. on the Boston Naming Test

Target	Response
toothbrush	tus brʌʃ
mushroom	rʊʃblʌn . . . brʌʃblu'n
camel	ka . . . kæ'nol
volcano	vɔlkæ'no . . . vɔlkæ'nənar . . . vɔlkæno
canoe	kovo . . . ko . . . kænbo
dominoes	painovðəz . . . painovəz . . . painovr
pelican	palækan
asparagus	harskəpus

the target. The relationship of these errors to the targets provides evidence that R.W. accessed a considerable amount of information about the phonological forms of words that he did not produce correctly.

PAL. R.W. was also tested on a psycholinguistically oriented aphasia battery, the Psycholinguistic Assessment of Language—PAL (Caplan, 1992)—in August, 1991. The PAL is designed to assess single word recognition, comprehension and word production from semantics in the auditory–oral and written modalities and repetition, oral reading, and writing to dictation. R.W.'s performance on the subtests of the PAL that test single word processing is summarized in Table 3. It should be noted that a group of normal control elderly subjects ($N = 57$) have been found to perform almost perfectly on these tasks. We shall outline the materials and methods used in those subtests of the PAL that are relevant to R.W.'s single word processing; for a fuller description of the PAL, see Caplan (1992).

Spoken Word Comprehension

The PAL tests relevant to spoken word comprehension include tests of phoneme discrimination, auditory lexical decision, and spoken word–picture matching. In all these tests, the experimenter was a woman speaker who read the stimuli aloud and whose lips were shielded from R.W.

Phoneme discrimination. The ability to discriminate phonemes was tested by a same–different task with 40 pairs of mono-syllabic non-words (20 different and 20 identical trials). Different stimuli differed in a single consonantal phoneme with respect to place of articulation, manner of articulation, or voicing. The changed phoneme occurred in stimulus-initial or stimulus-final position, either as a single consonant or as a member of a cluster. Subjects are required to indicate whether the two items are identical or different.

TABLE 3
Performance of Patient R.W. on Tests of Single Word Processing of the PAL

Test	Score
I. Spoken word comprehension	
i. Phoneme discrimination	33/40
ii. Auditory lexical decision	73/80
iii. Word-picture matching	29/32
II. Written word comprehension	
i. Written lexical decision	40/40
ii. Word-picture matching	32/32
iii. Attribute verification	44/48
III. Oral production	
i. Word and non-word repetition	
Words	2/20
Nonwords	0/20
ii. Word and non-word reading	
Words	21/32
Nonwords	16/25
iii. Picture naming	14/32
iv. Picture homophone matching	20/20

R.W. showed somewhat impaired performance on this test (33/40—19/20 correct “same” and 14/20 correct “different” judgments).

Auditory lexical decision. Auditory lexical access was assessed using a lexical decision task for words and specifically constructed non-words. The words consisted of 40 concrete nouns. They varied in frequency (>40/million or <5/million) and length (1 syllable versus 3 or more syllables). Half the foils were constructed by changing a single distinctive feature in a single phoneme in different syllabic positions in comparable words (e.g., *weeb* from *weed*). The other 20 foils were created by changing the form of words matched to the positive targets so as to resemble possible words (e.g., *harpisform* from *harpsichord*).

R.W. scored 73/80 (39/40 “yes” and 34/40 “no” responses correct) indicating that he recognizes and comprehends auditorily presented words well.

Spoken word-picture matching. Single word comprehension was assessed by using a word-picture matching test. Thirty-two concrete nouns were presented auditorily and R.W. was required to select one of two pictures as the match to the word. Foils were both semantically and visually similar to the targets (e.g., *deer* as target and *moose* as foil). Targets were of either high or low frequency, and were either short (mono-syllabic) or long (tri- or quadri-syllabic). They included examples from the categories of animals, fruits and vegetables, and tools. R.W. scored 29/32 on this task.

Together, the data from the tests on the PAL assessing auditory comprehension indicate that although R.W. showed somewhat impaired performance on the test of phoneme discrimination, his performances on auditory lexical decision and auditory word-picture matching indicated that he nonetheless recognized and comprehended auditorily presented words well.

Written Word Comprehension

The subtests of the PAL relevant to written word comprehension included written lexical decision, written word-picture matching, and a forced choice attribute verification procedure.

Written lexical decision. Lexical access from print was tested by a written lexical decision task. Word stimuli consisted of 32 common nouns that varied in frequency, abstractness, length, and orthographic-phonological regularity. An equal number of non-words were created by changing one letter in words appropriately matched to the target set. Stimuli were presented visually on cards in lowercase 24 point Geneva font and a yes/no (word/non-word) decision was required. R.W. was perfect at written lexical decision (40/40 items).

Word-picture matching and attribute-verification. Comprehension of written words was tested in two ways. The first was a word-picture matching test in which the words used were the foils in the auditory version of this task (see above) presented visually (lowercase 24 point Geneva font), with the same pairs of pictures used previously. The second was a forced-choice attribute-verification procedure. In this task, 16 concrete nouns were presented on cards in lowercase 24 point Geneva font, and three questions were asked regarding each noun. The questions required either a yes/no answer or the selection of one of two features (e.g., *Does a horse have fur or a hide?*). Across the 18 stimuli, an equal number of questions related to physical and to functional attributes. Nouns were from the categories of animals, fruits and vegetables, and tools and varied in familiarity. R.W. scored 32/32 on the word-picture matching task and correctly answered 44/48 forced-choice questions about written words on the PAL. These data indicate that he recognized and comprehended written words well.

Oral Production

Output phonological processing at the single word level was tested by the repetition, oral reading, and picture naming tests of the PAL. Responses were tape-recorded and errors transcribed off-line and classified non-exclusively into semantic errors, phonological errors, and apraxic/

dysarthric utterances by the examiner and one of the authors (D.C.) independently.

Word and non-word repetition. The repetition test involved repetition of both words and non-words. Twenty words—all common concrete nouns that varied in frequency and length—and 20 non-words derived by changing multiple distinctive features in words comparable to the word stimuli were presented auditorily, and R.W. was required to repeat them.

R.W. repeated only 2/20 words and 0/20 nonwords correctly. His errors were all phonological in nature, consisting of omissions, substitutions, and rare additions of phonemes and syllables. A few of these errors were phonologically related lexical items; some were quite distantly related to the target (e.g., *friend* → *spret*).

Word and non-word oral reading. In the oral reading task, 32 words, varied as to frequency, length, spelling-sound regularity, and abstractness were presented in written form on cards in lower case 24 point Geneva font. Twenty-five non-words derived by changing one letter in words that were matched to the word stimuli were also presented. R.W. was required to read each stimulus aloud.

R.W. read 21/32 words and 16/25 non-words aloud correctly, and there were no effects of frequency, length, or imagibility upon his reading aloud performance. There was an effect of spelling-sound regularity (13/16 regular words vs. 8/16 irregular words; $\chi^2 = 6.25$, $df = 1$, $p < .01$). Again, errors were phonological in nature, consisting mainly of substitutions of consonants. There were no regularization or lexicalization errors.

Picture naming. In the picture naming task, 32 line drawings of objects were presented for naming. The objects were the foils in the auditory word-picture matching test described above. The names were all common nouns, which varied as to semantic category, length, and frequency, as described above in the word-picture matching test.

R.W. named 14/32 pictures correctly, with no discrepancy in performance as a function of semantic class, word frequency, or length. R.W.'s errors were exclusively phonological, and consisted of substitutions, omissions, and additions of phonemes, and rarely, syllable deletions and additions.

The data from these subtests of the PAL show that R.W.'s output side processing at the single word level was abnormal. He made many errors on the repetition, oral reading, and picture naming subtests of the PAL. His errors on these tasks were almost exclusively phonological. However, there was no evidence of any misarticulation in R.W.'s speech in any of these tasks or in his spontaneous speech.

Picture homophone matching. The final test from the PAL that is relevant to R.W.'s single word processing is the picture homophone matching task. Thirty-two picture pairs were presented; half were homophones

(*bat*(baseball bat)/*bat*(winged mammal)) and half differed by a single distinctive feature (*cat/can*). R.W. was required to indicate whether the names of the pictures were homophones. He performed perfectly and answered immediately. Normal controls ($N = 57$) performed slightly worse than R.W. on this task (75% mean correct). This performance indicates that R.W. retained considerable information about the sounds of words and that he was able to access that information from a semantic representation, despite the fact that he could not produce comparable words normally.

Metalinguistic Phonological Awareness

Further investigation of R.W.'s ability to access lexical phonological information from a semantic representation was undertaken by asking R.W. to indicate his awareness of phonological features of words that he could not produce correctly. First, we attempted to establish whether R.W. knew the number of syllables in words that he did not name properly. He was asked to report the number of syllables in each word on the picture naming test of the PAL, administered on July 1, 1991, and he correctly reported the number of syllables in 17/18 items that he produced erroneously. On the third occasion on which he was given the Boston Naming Test (August 8, 1991), R.W. was consistently able to report correct values of phonological features that he misproduced (see Tables 4 and 5). These features extend to ones that are not usually available in the tip-of-the-tongue state, such as the nature of phonemes in unstressed second and third syllables of words with three or more syllables. The availability of this information strongly supports the view that R.W.'s disturbance in speech production arises after many aspects of word-form have been accessed.

Summary of Language Evaluation

Overall, R.W. largely retained his abilities to recognize and comprehend spoken words, and was excellent in recognition and comprehension of written words. He had a major disturbance of single word production. Six features of these data on word production allow us to characterize the locus of the functional disturbance in R.W. with reference to the models of speech production described in the introduction to this paper. First, R.W. made many phonological errors that involve the selection and ordering of the phonemes in the words he produced. This establishes his impairment as one affecting phonological, not semantic, processing. Second, he could accomplish picture homophone judgment extremely well; third, his errors in picture naming retained many phonological as-

TABLE 4
 R.W.'s Errors on the Boston Naming Test (8/8/91) and His Responses to Questions
 about Syllables in Words He Produced Erroneously, Indicating His Retained
 Knowledge of Aspects of Word Form

Target	R.W.'s oral production	R.W.'s answers to questions about			
		1st syl	2nd syl	3rd syl	other syl
octopus	oqubus. moqubus	*	E	E	n/a
pretzel	petzel	*	*	n/a	n/a
raquet	craquet	E	*	n/a	n/a
volcano	/vɔlkano ^w /	*	ca	no	n/a
seahorse	no response	*	morse	n/a	n/a
rhinoceros	shinoroso	shined	er	race	rus
escalator	elevator. calcator	el	can	tiv	E
stethoscope	ethoscope	*	*	scape	n/a
unicorn	hennicome	uni	corn	**	n/a
accordion	accodinin. accordin	*	*	en	E
latch	hatch, latch	*	n/a	n/a	n/a
tongs	tung, tongs	*	n/a	n/a	n/a
sphinx	fonix	/fo ^w /	nix	n/a	n/a
protractor	prakrattor, protraiktor	*	E	*	n/a
abacus	aba'cus	*	*	*	n/a

Note. C, correct; E, error; n/a, not applicable.

* Feature correct in R.W.'s initial utterance.

** Feature correct in one of R.W.'s responses.

pects of the target; fourth, he could provide information about phonological features of targets that he misproduced; and fifth, his errors occurred and had the same quality in all tasks requiring spoken output. These last four features indicate that he accessed phonological information that somehow became erroneous during the process of speech sound production. Finally, R.W. showed no signs of apraxia or dysarthria, for either correctly or incorrectly chosen and ordered phonemes. This indicates that his difficulty arose before the articulatory gestures associated with specific segments were planned and executed. We can conclude that R.W. accessed the forms of words in the phonological output lexicon, and that errors were introduced during the sound planning process.

ASSESSMENT OF VERBAL SHORT-TERM MEMORY, METALINGUISTIC PROCESSING OF SINGLE WORDS, AND ARTICULATORY RATE

As discussed in the introduction to this paper, rehearsal is thought to be involved in the production of the word length effects in auditory and

TABLE 5
 R.W.'s Errors on the Boston Naming Test (8/8/91) and His Responses to Questions about Phonemes in Words He Produced Erroneously,
 Indicating His Retained Knowledge of Aspects of Word Form

Target	R.W.'s oral production	1st C	R.W.'s answers to questions about					Number of syllables
			1st C, 2nd syllable	1st C, 3rd syllable	Last C	V 2nd syllable	V 3rd syllable	
octopus	oqubus, moqubus	*	C	C	*	*	*	*
pretzel	petzel	*	*	n/a	*	*	n/a	*
raquet	craquet	E	*	n/a	*	*	n/a	*
volcano	/vɔlkano**/	*	*	*	n/a	*	*	*
seahorse	no response	C	C	n/a	C	C	n/a	1
rhinoceros	shinoroso	C	E /k/	C	E /n/	E /ε/	E /o/	5
escalator	elevator, calcator	C	C	E /t/	*	C	C	3
stethoscope	ethoscope	C	E /s/	C	*	C	*	C
unicorn	hennicome	C	*	*	C	*	*	2
accordion	accodinin, accoridin	*	E /r/	E /n/	C	C	C	4
latch	hatch, latch	*	*	n/a	*	n/a	n/a	*
tongs	tung, tongs	*	*	n/a	*	n/a	n/a	*
sphinx	fonix	E	*	*	*	n/a	n/a	2
protractor	prakrattor, protraiktor	*	*	*	*	*	*	*
abacus	aba'cus	*	*	*	*	*	*	*

Note. C, correct; E, error; n/a, not applicable.

* Feature correct in R.W.'s initial utterance.

** Feature correct in one of R.W.'s responses.

visual span tasks, the phonological similarity effect in visual span, and in written rhyme judgments. Rehearsal is also thought to be involved in improving performance on Brown–Peterson tasks with unfilled intervals compared to these tasks with filled intervals. The following tests were used to assess these functions.

Assessment of Memory Span

The stimuli and procedures used were identical to those used in a previous study of brain-damaged patients with apraxia of speech (Waters, Rochon, and Caplan, 1992). The stimuli for the word span tasks were drawn from a pool of 175 monosyllabic, picturable words. These words were chosen so that they would be similar in terms of frequency of occurrence to the stimuli used for the tasks outlined below assessing the effects of word length and phonological similarity. The frequency of occurrence of the words in this pool ranged from 1 to 431, with a median frequency of 13 ($SD = 42.2$) (Kucera & Francis, 1967). An auditory and a visual version of the word span test were constructed in which there were ten trials at each of the span sizes from 2 to 9. The same stimuli were used for the two versions at each span size but the items were presented in a different random order. The median frequencies of the stimuli used at each span size ranged from 13 to 145. No stimuli were repeated at a given span size, and the items within a trial were chosen so as to be phonologically and semantically different.

Words were presented either auditorily or printed in lower case letters on cards. On each trial, the items were presented at the rate of one item per second. After presentation of the items to be remembered, subjects were shown a page on which line drawings of the words just presented, as well as one additional item from the set, were arranged in random order. Subjects were required to point to the items which had been presented in the order of presentation. They were always required to point to the same number of items as had been presented, so that there were no omissions (e.g., at span size three subjects were required to point to three items). Subjects were permitted to repeat responses. Testing began with sequences of two items (span size two) and was discontinued when subjects recalled the items in the correct serial order on 3/10 or fewer trials at a given span size. Subjects' span was considered to be the largest span size at which they reported the items in the correct serial order on 6/10 trials. The percent of items which subjects recalled in the correct serial order was also scored at each span size in order to determine the span size at which each subject would be tested on the memory measures outlined below.

Effect of Word Length and Phonological Similarity on Span

The effects of word length and phonological similarity on auditory and visual span were investigated using the same stimuli and procedures as in a previous study of patients with apraxia of speech (Waters et al., 1992). Subjects heard or saw a series of words presented one at a time and were then required to point to pictures corresponding to these words in the order they were presented in a display containing one more picture than in the presented list. This picture was drawn from the set of items of each type (long, short, phonologically similar, phonologically dissimilar). For word length effects, one-syllable words were compared with three-syllable words. The one-syllable words were taken from the set *tray, van jug, paw, tub, skirt, frog, pig* and the three-syllable words from the set *submarine, magazine, skeleton, musician, potatoes, kangaroo, telescope*. The median frequency of the one-syllable words was 10.5 ($SD = 10.4$) and of the three-syllable words was 14.0 ($SD = 13.4$). For phonological similarity effects, phonologically similar words were compared with phonologically non-similar words. The phonologically similar sequences were chosen from the set *mat, fat, pat, cat, can, pan, man, fan* and the dissimilar sequences from the set *net, two egg, fox, pen, bed, hat, jug*. The median frequency of the phonologically similar items was 29 ($SD = 694$) and of the dissimilar items was 18 ($SD = 470$).

Span tasks that present words as stimuli and in which subjects must point to pictures do not necessarily require lexical phonological access—i.e., the activation of phonological representations from semantics—as part of the rehearsal process. For both auditorily and visually presented words, the surface forms of phonological representations can be accessed directly from the input without contacting semantic representations. These can be rehearsed and used to access the meaning of the presented words, which can then be matched to the presented pictures (we take up the question of whether this is how this task is performed in our final discussion). Therefore, we also used a purely pictorial version of the span task with patient R.W. In this version of the task, subjects were presented with sequences of pictures, the words corresponding to which were either long or short, or phonologically similar or dissimilar. Subjects were given instructions regarding what word was associated with each picture. Subjects were then required to indicate the sequence of pictures that were presented, using a picture pointing task as in the word span tasks. Though this task could in principle be accomplished by a purely visual process, Schiano and Watkins (1981) have reported effects of word length and phonological similarity in this task, indicating that subjects activate word forms and use verbal short term memory in this task. In this task, these word forms must be activated from semantics, thereby affording a subject the opportunity to use an underlying phono-

logical representation as the basis for rehearsal if such a representation is sufficient to allow rehearsal to occur.

An important methodological issue is how to determine the span size at which subjects should be tested for these effects. In some studies, all subjects are tested at a common span size. The problem with this procedure is that some subjects will be at floor and others at ceiling. In order to circumvent this problem, subjects were tested for the effects of word length and phonological similarity on span at the span size at which they had correctly reported 60% of the items in the correct serial order in the corresponding modality on the word span task outlined above. This procedure helps to eliminate floor and ceiling effects and, although subjects are tested at different span sizes, the task is presumably at a comparable level of difficulty across subjects. Subjects were tested on 20 trials of short words and 20 trials of long words and pictures, and 20 trials of non-rhyming and 20 trials of rhyming words and pictures, at the appropriate span size in each of the auditory and visual modalities.

Brown–Peterson Task

Monosyllabic words drawn from the same pool as the short, phonologically dissimilar, words used in the spans tasks described above, were selected. Words were presented auditorily in blocks of twenty pairs for each memory interval, and the subject was requested to repeat them after filled or unfilled intervals of 3, 6, and 9 sec. During the filled intervals, the subject was required to name colored dots.

Rhyme and Homophone Judgment

The stimuli and procedure for the rhyme judgment and homophone tasks were those used by Waters et al. (1992). Stimuli for the rhyme judgment task consisted of 80 pairs of words. These word pairs were of four types—orthographically similar rhymes (e.g., *best/west*), orthographically dissimilar rhymes (e.g., *door/war*), orthographically similar nonrhymes (e.g., *farm/warm*), and orthographically dissimilar nonrhymes (e.g., *farm/war*). One quarter of the stimuli were of each type. The four types of stimuli were matched for frequency of occurrence, with the median frequency of the words in this task being 57.5 (Kucera & Francis, 1967). The auditory and printed versions of the task were carried out separately. On each trial subjects were presented with a pair of words either orally or in print and were required to indicate by pointing to one of two response cards whether the words rhymed.

For the homophone judgment task, subjects were presented with 70 pairs of words and were required to indicate on each trial whether the two words sounded the same or different. On half of the trials the words

were the same and on half they were different. The words used for the "same" trials were all homophones (e.g., *poll/pole*). The "different" word pairs were minimally phonologically different and were non-homophones (e.g., *spit/spin*). The homophone and non-homophone pairs were matched for frequency of occurrence, with the median frequencies being 42 and 43, respectively (Kucera and Francis, 1967). In addition, since the same stimuli were also presented visually, to ensure that the members of the homophone pairs did not look more alike than the members of the non-homophone pairs, the pairs of words used across the two types of stimuli were developed in matched sets, such that the position and number of shared letters for each pair in the homophone condition was identical to a pair in the non-homophone condition. For example, the first three letters were the same in the two members of the homophone pair *poll-pole*, and in its matched non-homophone pair *spit-spin*. Procedure was the same as in the rhyme judgment task.

Articulation Rate

Articulation rate was measured for a subset of the short and long words used in the span task. Subjects were presented with a pair of items and were instructed to repeat the items continuously as fast as possible, until asked to stop. Time taken for 10 repetitions of the pair was recorded. On three trials the stimuli consisted of short words (*frog-paw*, *jug-tray*, and *pig-skirt*) and on three trials they were long words (*kangaroo-skeleton*, *telescope-computer*, *submarine-musician*). The data across the three trials of each type were averaged to yield a mean articulation rate for each subject.

RESULTS OF ASSESSMENT OF SHORT-TERM MEMORY, METALINGUISTIC PROCESSING, AND ARTICULATORY RATE

Normal Control Subjects

Waters et al. (1992) tested ten control subjects (9 females and 1 male) who ranged in age from 59–74 (mean = 64 ± 5) on all the experimental measures used in the present study, except for picture span. The mean auditory and visual word spans for these subjects were 5.1 and 4.7, respectively. All of the control subjects showed statistically reliable effects of word length and phonological similarity in the span tasks. Their mean number correct on the auditory and visual rhyme and homophone judgment tasks was 96.2, 92.2, 97.9, and 97.5%, respectively. Articulatory rates were 6.1 ± 1 sec to repeat two short words ten times and 8.58 ± 11.3 sec to repeat two long words 10 times.

For the picture span tasks, 10 additional subjects were tested. The mean number of items correct for picture span was significantly greater for phonologically dissimilar picture lists than phonologically similar lists ($t = 4.64, p < .001$) and for short picture lists than for long picture lists ($t = 2.98, p < .01$).

Case R.W.

R.W. was tested on all the tasks assessing short term memory and metalinguistic processing except picture span in July, 1991.

Performance on verbal span with pointing responses. R.W.'s auditory word span was determined to be 3 (7/10 lists correct for 3 item lists; 0/10 lists correct for 4 item lists), and his visual word span to be 2 (8/10 lists correct for 2 item lists; 5/10 lists correct for 3 item lists). He achieved 25/30 (83%) and 16/40 (45%) correct for auditorily presented lists at span sizes 3 and 4, respectively, and 19/30 (63%) and 22/40 (55%) correct for visually presented lists at span sizes 3 and 4, respectively. Accordingly, he was tested on 3 item lists with the phonological similarity and word length materials in both the auditory and visual modalities. Results are shown in Fig. 2.

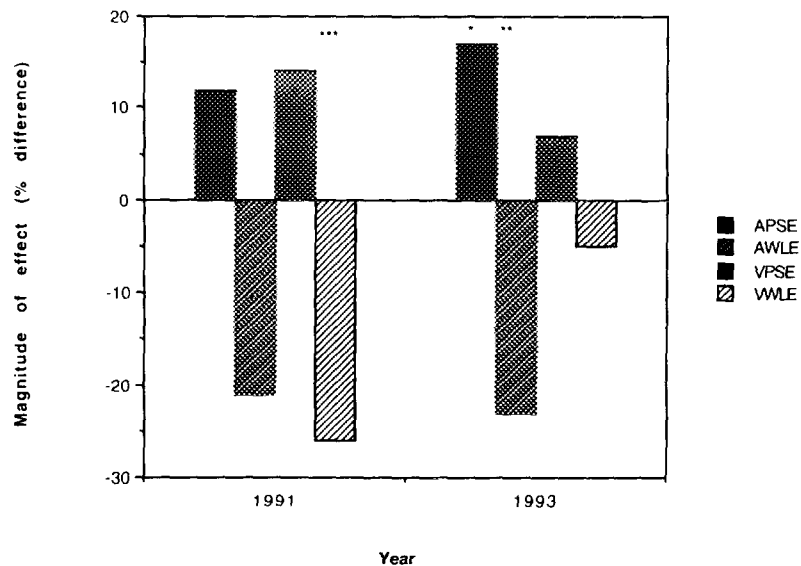


FIG. 2. Performance of R.W. on span tasks. APSE, auditory phonological similarity effect; AWLE, auditory word length effect; VPSE, visual phonological similarity effect; VWLE, visual word length effect. *** Significant at $p < .001$; ** significant at $p < .01$; * significant at $p < .05$.

R.W.'s performance on these materials was analyzed for each modality using 2×2 chi square analyses (correct/incorrect \times similar/dissimilar, and correct/incorrect \times long/short), in order to determine whether there was a statistically reliable effect on each of the four tasks. The effect of phonological similarity was not significant (auditorily presented lists with phonologically similar words: 23/60; auditorily presented lists with phonologically dissimilar words: 33/60; $\chi^2 = 2.7$; ns; visually presented lists with phonologically similar words: 44/60; visually presented lists with phonologically dissimilar words: 52/60; $\chi^2 = 2.5$; ns). The "reversed" effect of length was only at the level of a trend in the auditory modality (auditorily presented lists with short words: 26/60; auditorily presented lists with long words: 37/60; $\chi^2 = 3.3$; $p = .07$) but was highly significant for visually presented lists (visually presented lists with short words: 42/60; visually presented lists with long words: 58/60; $\chi^2 = 13.5$; $p < .001$).

R.W. was retested on these material in May and June, 1993, at a time when he showed residual problems with word production. He was retested on the PAL at this time. He repeated 13/20 words and 2/20 non-words correctly, and named 29/32 pictures and read 55/57 words and non-words aloud correctly. Thus, he continued to show deficits in repetition, though both his picture naming and oral reading had improved.

R.W. was retested for span on medium frequency words in 1993 to establish his baseline for span testing. He scored 20/20 at span size 2 and 12/30 (40%) at span size 3 for auditorily presented lists and 30/40 (75%) at span size 4 and 25/50 (50%) at span size 5 for visually presented lists. Accordingly, he was tested for the effects of phonological similarity and word length on span on 3-item lists in the auditory modality and on the 5-item lists in the visual modality. Results are shown in Fig. 2. The effect of phonological similarity was significant in the auditory modality (auditorily presented lists with phonologically similar words: 43/60; auditorily presented lists with phonologically dissimilar words: 53/60; $\chi^2 = 4.2$; $p < .04$) but not in the visual modality (visually presented lists with phonologically similar words: 51/100; visually presented lists with phonologically dissimilar words: 58/100; $\chi^2 = .7$; ns). The "reversed" effect of length was significant in the auditory modality (auditorily presented lists with short words: 37/60; auditorily presented lists with long words: 51/60; $\chi^2 = 7.2$; $p < .01$) but not in the visual modality (visually presented lists with short words: 37/100; visually presented lists with long words: 42/100; $\chi^2 = .7$; ns).

Performance on picture span with pointing responses. R.W. was tested on the picture span tasks in September, 1992. Prior to this testing, he was retested on the PAL in May, 1992 and showed deficits in repetition (8/20 words and 0/20 nonwords correctly repeated), and picture naming and oral reading that had improved since 1991 (28/32 and 54/57 correct, respectively).

R.W. was retested for span on medium frequency words to establish his baseline for span testing. He scored 20/20 (100%) at span size 2 and 12/30 (40%) at span size 3 for auditorily presented lists and 30/40 (75%) at span size 4 and 25/50 (50%) at span size 5 for visually presented lists. In order to ascertain whether he still showed an impairment of rehearsal in span, he was retested for the effects of word length on span. For auditory span, he was tested at a span of two, and showed no length effect (33/40 for short words and 38/40 for long words; $\chi^2 = 2$; ns). For written span, he was tested at a span of four and showed a trend toward a reversed length effect (29/80 for short words and 41/80 for long words; $\chi^2 = 3.07$; $p = .08$). These results indicate that R.W. showed impaired rehearsal in span tasks at that point in time.

Since there was no pretest corresponding to the medium frequency word span task on which to establish R.W.'s baseline, he was tested for phonological similarity and word length effects on the picture span task at span size 4. He obtained a score of 47/80 for pictures with phonologically dissimilar words and 41/80 for pictures with phonologically similar words ($\chi^2 = .6$; ns), and 47/80 for pictures with long words and 45/80 for pictures with short words ($\chi^2 = .02$; ns). The lack of either a word length or phonological similarity effect in this task is consistent with the absence of rehearsal on this task.

R.W.'s performance in the Brown Peterson task is shown in Fig. 3. Though his absolute level of performance was somewhat better with a

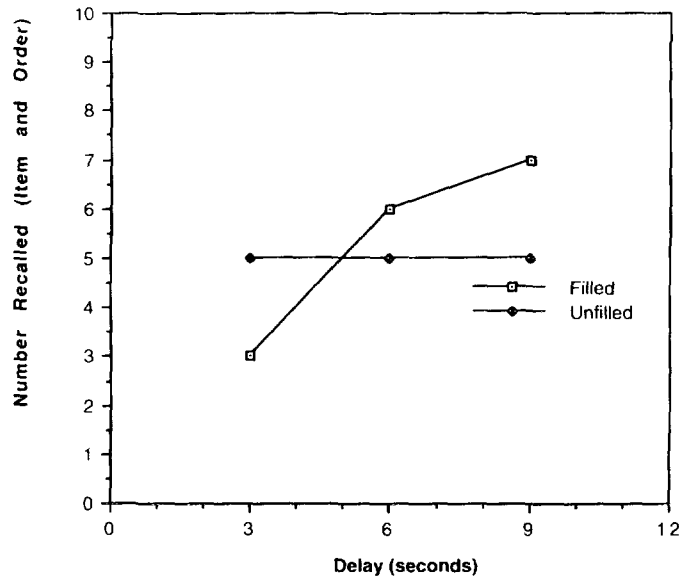


FIG. 3. Performance of R.W. on Brown Peterson task.

filled than an unfilled delay, $2 \times 2 \chi^2$ analyses (correct/incorrect \times filled/unfilled delay) showed no significant effect of delay type on his performance at any delay interval.

R.W.'s performance on rhyme and homophone judgments is shown in Table 6. He was nearly perfect on homophone judgments, but very impaired on rhyme judgments in both the auditory and visual modalities.

R.W.'s articulatory rate was 23 sec for 10 repetitions of two short words and 39 sec for 10 repetitions of two long words. This rate is well outside the normal range, and comparable to that of the moderately impaired patients with apraxia of speech in the Waters et al. (1992) study. The reason for this slow articulatory rate was that R.W. had great difficulty in producing the correct forms of the stimuli because of the phonological errors he made.

DISCUSSION

The performance of the patient described here sheds light on the mechanism of verbal rehearsal. R.W. showed evidence of being able to activate lexical phonological representations. However, he was unable to produce correct phonological forms of words or nonwords. His disturbed speech production was not dysarthric or apraxic, but consisted of properly articulated, mis-chosen and mis-ordered phonological segments and misstructuring of the syllabic forms of words. The locus of his impairment can be identified as a stage of speech output planning that changes and/or adds to the phonological representations that are initially activated from semantics.

R.W. was unable to use rehearsal processes normally in verbal short-term memory. He had a reduced span, comparable in magnitude to those that have been found in other patients with speech output problems that affect rehearsal (patients with apraxia of speech—Waters et al., 1992). He showed no word length effects in span tasks with auditorily or visually presented words. He showed neither the normal word length nor phonological similarity effects in a picture span task. He showed no difference between filled and unfilled conditions in the Brown–Peterson task.³ He could make written homophone but not rhyme judgments. These performances are strong indications that R.W. was not using rehearsal mechanisms normally while accomplishing these tasks. Before discussing the implications of these results for the nature of the rehearsal process, we

³ R.W. showed improvement over the three intervals on the B-P task with filled delays. Though this improvement is statistically insignificant, it is surprising, and we have no obvious explanation for it. However, even considering this feature of R.W.'s performance on the STM tasks we tested him on, the overall pattern of his performance strongly suggests that he does not rehearse properly.

TABLE 6
Performance on the Rhyme and Homophone Judgment Tasks

	Auditory rhyme judgment	Visual rhyme judgment	Auditory homophone judgment	Visual homophone judgment
R.W. (7/91)	63%	70%	94%	100%

turn to three features of the data that deserve comment: the pattern of phonological similarity effects in span tasks, the reversed word length effect in span tasks, and the absence of an auditory rhyme effect.

The pattern of phonological similarity effects seen in the span tasks in R.W. is relevant to the mechanism that underlies this effect. Towards the onset of his illness, R.W. did not show an effect of phonological similarity for both auditory and visual word lists. As he improved, the phonological similarity effect clearly emerged in the auditory modality. In our study of patients with apraxia of speech (Waters et al., 1992), we found that some patients with severe rehearsal problems lost the auditory phonological similarity effect, and we entertained the possibility that this was due to their rehearsal impairment. We do not wish to challenge the theory that holds that a phonological store and a rehearsal mechanism are both involved in rehearsal. However, we are arguing that the two interact closely, such that the former depends upon the latter as well as vice versa (see Longoni, Richardson and Aillo, 1993). The pattern in R.W.—the appearance of a clear auditory phonological similarity effect as his phonological word production improved—is consistent with this view that the rehearsal impairments can affect the auditory phonological similarity effect.

R.W. showed a reversed length effect in both auditory and visual span, which was statistically significant with auditory presentation on one occasion and with written presentation on another occasion. Though the fact that the significance of the effect varied as a function of modality of list presentation on different test occasions requires that the effect be interpreted cautiously, the fact that the effect was always present in this reversed direction provides reasonably strong evidence that it is a real phenomenon that requires an explanation. One speculation is that, if a subject cannot rehearse words effectively in short-term memory and relies upon phonological representations in a phonological store in STM tasks, the similarity of those representations to other words in the language may affect performance. If so, the increased distinctiveness of longer words, compared to shorter words, with respect to the cohort of lexical items of a given length might increase the strength of their traces in short term memory.

R.W. showed an inability to make rhyme judgments for auditory as well as printed words. Articulatory suppression has been shown to interfere with visual rhyme judgments but to the best of our knowledge there is no data on the effect of articulatory suppression on auditory rhyme judgments. Besner (1987) has suggested that articulatory suppression interferes with operations performed upon a lexical code. The retention or comparison of phonemic segments in memory required to make rhyme judgments may be among these operations. The difficulty R.W. had with rehearsing may have been of sufficiently great severity and/or of such a qualitative nature as to interfere with this function even when words were presented auditorily. Homophone judgments, which are not affected by articulatory suppression and which were intact in R.W., do not require that the phonological structure of a word be segmented and thus are thought not to require rehearsal to the same degree as rhyme judgments.

We now turn to the implications of these results for the nature of the rehearsal process.

The first implication of these results (consistent with the data from normals and other patients) is that verbal rehearsal does not involve input-side lexical processing. R.W. had no significant impairments of word recognition or comprehension, yet the ability to process words at these levels of function was insufficient to sustain verbal rehearsal. These results thus confirm the wealth of data that indicate that verbal rehearsal involves speech output processing.

The data also suggest that the ability to access a lexically listed phonological representation is not adequate to support rehearsal. Just as the fact that R.W.'s intact word recognition and comprehension indicates that the integrity of input-side phonological processing is not sufficient to support rehearsal, the fact that this patient could access many aspects of word form in speech production but not rehearse indicates that the ability to access lexical phonological representations is not sufficient for rehearsal.

One might object to this latter conclusion on the grounds that neither span tasks nor the metalinguistic tasks involving single words used here require the activation of phonological representations from semantics as part of the rehearsal process. Therefore, one might argue, R.W.'s relatively high degree of preservation of the ability to access phonological representations from semantics is not relevant to the role that this aspect of word sound production plays in rehearsal.

Three considerations blunt this concern. The first is that the span tasks that were used to test R.W. involved a pointing response to pictures. To accomplish this task, a subject must achieve a match between the presented words and pictures. This may be done either by (1) finding the name for a presented picture and matching it to a word that is maintained

in short-term memory or (2) by accessing semantics from the presented word (either when the word is first presented or while it is being maintained in short term memory and the pictures are being inspected). The first of these mechanisms clearly involves the stage of lexical phonological access, and it has been argued that the second involves accessing an underlying phonological representation as well (Lahiri & Marslen-Wilson, 1991). Since the phonological planning process was disrupted in R.W., he may have tried to accomplish the span tasks in part by using these accessed phonological representations as the basis for rehearsal. The fact that rehearsal was impaired indicates that no such process was used or that it was ineffective. This may have been because R.W. did not use these representations as the basis for rehearsal on a strategic basis, or it may be a reflection of the fact that no such strategy is possible because the representations that are activated by lexical phonological access alone—divorced from phonological planning—cannot support rehearsal.

Second, it is not clear that the repetition, transcoding, and metalinguistic aspects of the tasks that we used to test rehearsal do *not* involve lexical phonological access. If we subscribe to a model of word production that includes several stages of word sound activation from semantics, we may ask what stages of phonological output processing are involved in speech tasks in which the phonological form of a word need not be accessed from semantics—e.g., repetition and reading aloud of words and nonwords, the spontaneous production of nonwords, rhyme, and homophone judgments, etc. One of the authors (DC) and his colleagues have elsewhere suggested that these tasks can—and usually do—involve activating the same underlying phonological representations as does word production from semantics (Beland et al., 1990; Caplan, 1992). The argument is based on the observation that aphasics' errors attributable to the conversion of underlying phonological representations to surface phonological representations have been described in repetition and reading aloud tasks (Beland et al., 1960; Schnitzer, 1972), suggesting that underlying phonological representations are involved in these tasks (see Caplan, 1992, Chapter 4, for discussion). According to the model we have proposed, oral word production may—and usually does—involve computation of an abstract phonological representation, even if the task in which it occurs does not involve semantics. If this is an appropriate model of these processes, the failure of the patient reported here to show signs of rehearsal in span and metalinguistic tasks suggests that rehearsal cannot take place on the basis of an underlying phonological representation.

Finally, R.W. did not show either word length or phonological similarity effects in a picture span task. These effects have been reported in previous research (Schiano & Watkins, 1981) and were present in a normal group of subjects tested on the materials used with R.W. These

effects are eliminated by articulatory suppression (Schiano & Watkins, 1981). The presence of word length and phonological similarity effects in picture span tasks indicates that these tasks are verbally mediated. The lexical items that provide the basis for this verbal mediation must be activated from semantics on the basis of the visual analysis of pictures, and therefore the process of lexical phonological activation must take place during this task. The elimination of these effects by articulatory suppression in normals suggests that the tasks make use of verbal rehearsal. The absence of these effects in R.W. thus indicates that accessing underlying lexical phonological representations does not provide a sufficient phonological substrate for verbal rehearsal to occur.

The data indicate that R.W.'s disturbance arises at the planning stage of output phonological processing. Accordingly, the fact that he has a disturbance of verbal rehearsal provides evidence in support of the hypothesis that phonological speech planning is involved in rehearsal. The results from this patient suggest that verbal rehearsal requires those abstract mental processes involved in elaborating and otherwise changing phonological representations in the phonological output lexicon into a form needed in programming the articulators. It will be important to determine whether similar results are found in other patients with similar sorts of speech output disorders. At this point, considering both the present results and the data described above regarding retained rehearsal in patients with dysarthria and impaired rehearsal in patients with apraxia of speech, the neuropsychological data specify what might be thought of as an upper and a lower bound to the speech production processes involved in verbal rehearsal. They provide evidence supporting the claim that activating lexical phonological representations in the phonological output lexicon—though perhaps necessary—is not sufficient, and that producing articulated utterances is not necessary for verbal rehearsal to take place.

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