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SHORT-TERM MEMORY DefICITS AND LONG-TERM LEARNING: BEYOND PHONOLOGY

by

MONICA LYN FREEDMAN

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

MASTER OF ARTS

APPROVED, THESIS COMMITTEE

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Houston, Texas

May, 1998
ABSTRACT

Short-term Memory Deficits and Long-term Learning: Beyond Phonology

by

Monica Lyn Freedman

Short-term memory (STM) is comprised of dissociable phonological, semantic and syntactic components (Martin, 1993). Previous findings indicate phonological STM capacity supports learning of novel phonological forms, such as new vocabulary (e.g., Baddeley, 1998). It was hypothesized that semantic STM capacity supports learning of novel semantic information. Ability to learn novel phonological vs. semantic information was compared in six aphasic patients using a paired associated paradigm. It was predicted that patients with phonological STM deficits would be most impaired at learning novel phonological information, whereas patients with semantic STM deficits would show the reverse pattern. Predictions were confirmed for four patients. However, two patients failed to show learning for either type of material. Results suggest that the semantic and phonological components of STM are essential for learning corresponding representations in long-term memory. Patients were also tested on adjective-noun pairs with varying degrees of pre-existing association. Results suggest that phonological STM supports learning of abstract stimuli.
Acknowledgments

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Phonological Processing and STM
Semantic Processing and STM
Composite Scores
Long-term Learning
Discussion

Patient ML

Phonological Processing and STM
Semantic Processing and STM
Composite Scores
Long-term Learning
Discussion

Patient AK

Phonological Processing and STM
Semantic Processing and STM
Composite Scores
Long-term Learning
Discussion

Patient GR

Phonological Processing and STM
Semantic Processing and STM
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Phonological Processing and STM
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RELATION OF SHORT-TERM MEMORY TO LONG-TERM MEMORY

Historically, the predominant models of memory advocated a separation between short-term memory (STM) and long-term memory (LTM). These theories maintained that information must undergo necessary processing in STM in order to proceed to LTM, where it could be retained indefinitely. Consistent with the separation of the two memory systems was evidence that amnesic patients had normal STM capacities in spite of very impaired LTM capacity. However, other patients demonstrating the reverse dissociation of preserved LTM and impaired STM challenged the assumption that information had to be maintained in STM prior to registration in LTM. The following research investigates the relationship between STM and long-term learning. The position taken here is that there are different components of STM (R. Martin, 1993; R. Martin & Romani, 1994; R. Martin, Shelton, & Yaffee, 1994; N. Martin & Saffran, 1998) which are related to the retention of specific codes, and short-term retention of these codes is necessary for their long-term learning.

The first study that directly challenged this idea that processing in STM was a prerequisite for long-term learning involved patient KF (Warrington & Shallice, 1969) who had sustained a lesion to the left parietal lobe and suffered from a severe deficit in verbal STM. He was almost completely unable to repeat back verbal material, having word and digit memory spans between one and two items. The most impressive feature of KF's condition was his relatively unimpaired verbal learning despite severely impaired verbal STM.

Warrington and Shallice (1969) assessed the patient's long-term learning abilities using a paired associate task, in which pairs of items
are presented in a study phase and then, in a later test phase, the subject is presented with the first item of the pair and tries to produce the second item. KF demonstrated normal paired associate learning on an early version of the Wechsler Memory Scale (Wechsler, 1945) and was also above average in learning 10 word lists. These findings were replicated in a subsequent study (Warrington, Logue, & Pratt, 1971) which tested two other patients along with KF. Each patient had a greatly reduced auditory verbal memory span, but normal performance on paired associate learning, short story recall, and 10 word list learning, thus supporting the claim that long-term learning could occur despite impaired functioning of STM processes.

Results from numerous studies suggest that long-term learning in the kinds of paradigms investigated by Warrington et al. (1971) depends on the retention of semantic codes (e.g., Baddeley & Dale, 1966; Kintsch & Bushke, 1969) whereas memory span depends mainly on a phonological code (e.g., Baddeley, Thomson, & Buchanan, 1975; Conrad & Hull, 1964; Hintzman, 1965; Luce, Feustel, & Pisoni, 1983; Schweickert & Boruff, 1986; Sperling & Speelman, 1970). Thus, the dissociation between impaired STM and preserved LTM might be re-interpreted in terms of a coding distinction. That is, these patients might have difficulty retaining phonological information over the short-term, but perhaps do not have difficulty retaining other types of information such as visual or semantic. Consequently, their good long-term learning could be attributed to their preserved ability to retain semantic codes.

If so, then a different pattern might emerge if the stimuli to be learned were new words, or equivalently, nonwords. That is, one
might expect that an inability to retain phonological information over the short term would result in impaired ability to learn novel phonological forms, such as new words. Evidence consistent with this type of thesis was obtained by Gathercole and Baddeley (1989) from a longitudinal study of the relationship between phonological STM and vocabulary development in children. They tested children during their first month in school and one year later on vocabulary, nonverbal skills, single word reading, and nonword repetition. The nonword repetition task was used to measure short-term phonological retention ability. After partialling out age and nonverbal ability, the researchers found that the children's nonword repetition ability was a good predictor of their vocabulary knowledge. Nonword repetition ability in the first year retained its predictive value for vocabulary knowledge one year later, even after vocabulary knowledge from the previous year was also partialed out. Thus, they concluded that vocabulary development depends on phonological STM which mediates the long-term storage of phonological information. To learn new words, one must acquire a long-term semantic representation of the underlying concept and match that to a novel phonological sequence. Thus, inability to retain the novel phonology interferes with the ability to learn the new words, even if the semantic representation can be acquired.

In a later study, Gathercole and Baddeley (1990) examined six children who had a developmental language disorder. Features of this disorder are normal nonverbal intelligence coupled with impaired language development and STM skills. After discounting other possible causes of the children's poor STM performance, Gathercole and
Baddeley concluded that the children with developmental language disorder suffered from a selective deficit of phonological memory skills.

Further evidence of a relation between phonological STM and learning of new phonological forms has been obtained in studies of patients with phonological STM deficits. Baddeley, Papagno and Vallar (1988) studied patient PV who had a selective impairment of auditory verbal memory with a span of just two to three digits, letters, or words. Her verbal comprehension was good, except when understanding required maintenance of the surface structure of the sentence across several intervening words. Also, when asked to repeat spoken nonwords, the patient performed perfectly only with individual nonwords of one syllable. Increasing the number of nonwords in the sequence or the number of syllables in the nonwords greatly increased her error rate. She was perfect, however, in reading nonwords at any length.

Despite her poor performance on these tasks involving phonological STM, PV performed at a normal level for learning paired-associates consisting of concrete words. Presumably, the patient was able to rely on semantic coding to remember the meaningful stimuli. When the paired-associates consisted of one meaningful word paired with a foreign word (Russian, but pronounceable in her native Italian), she failed to recall any item in any of the 10 trials. This complete lack of learning persisted even when the rate of presentation was slowed down.

PV's inability to retain phonological information accounts for her inability to repeat back nonwords with several syllables and her
inability to learn word-nonword pairs auditorily, which would require maintenance of the incoming novel phonology. Her capacity to learn associations between meaningful words suggests a reliance on semantic coding for retention of the individual words. Thus, PV's performance suggests that short-term phonological storage is essential for learning unfamiliar verbal material, but not for establishing associations between meaningful items.

**DISSOCIABLE COMPONENTS OF SHORT-TERM MEMORY**

Current research indicates that there are other components to working memory beyond the phonological component, which have not been accounted for in most models of working memory (e.g., Baddeley & Hitch, 1974; Baddeley, Gathercole and Papagno, 1998). Namely, there is evidence for the separate retention of semantic and syntactic information, both dissociable from phonological retention (R. Martin, 1993). In contrast to PV, who demonstrated a phonological retention deficit, other patients have been reported with different deficits, such as in the short-term retention of semantic information (R. Martin & Romani, 1994; R. Martin, Shelton, & Yaffee, 1994; N. Martin & Saffran, 1998). Selective deficits to these different components should differentially affect learning performance according to the material which is to be learned. Just as a phonological retention deficit adversely affects the learning of novel phonological information, a semantic retention deficit should adversely affect the learning of novel semantic information.

N. Martin and Saffran (1998) studied fifteen patients with severely impaired STM spans (between one and three items for words) and repetition abilities. These patients demonstrated varied
patterns of semantic and phonological processing abilities, which Martin and Saffran claim are related to short- and long-term retention. They showed that the patients' performance on list repetition was more affected by variables related to the capacity which was best preserved. For example, primacy and imageability effects are generally attributed to the semantic processing system, while recency effects reflect phonological STM and frequency effects reflect lexical processes at the level of the phonological word form. Their finding suggests that different components of language processing contribute to verbal STM tasks, or in other words, correlate to such components of STM. The patients were selected for participation in the study based on the criteria that they not only exhibited repetition and STM impairments, but also experienced difficulty with naming. It is unclear, therefore, whether the semantic deficit demonstrated by some of the patients in the study was attributable to an impaired component of STM, or rather, to impaired semantic processing at a more basic level. Martin and Saffran would claim that impaired STM and processing are simply points on a continuum of impaired language processing. Thus, STM deficits would occur even with mild impairment whereas basic processing difficulties would be at the more severe end of the impairment spectrum.

The present viewpoint advocates a separation of pure semantic and phonological processing abilities from STM capacity, such that a patient with impaired semantic STM capacity might still demonstrate intact semantic processing abilities (i.e., in naming or picture matching tasks). Specifically, verbal STM is considered a limited-capacity buffer which holds the representations which are created as output from
language processing (Martin & Lesch, 1996). Clearly it is difficult to distinguish between these two conceptualizations, in the sense that neither theory would predict preserved STM capacity in the face of severely impaired language processing. Such a case would require the retention of information which is not even understood, or in other words, which enters the STM buffer in a degraded state. This distinction is not absolutely critical for the purposes of the present research, except that patients most suitable for this study are those who demonstrate a deficit in one component of STM capacity (either semantic or phonological) coupled with intact language processing. Thus, the relationship between the impaired component of STM and learning ability for different types of material (semantic vs. phonological) can be investigated while ruling out possible alternative explanations of impaired processing of the information during presentation. Preliminary data from current investigation (N. Martin, 1998) of the relationship between STM abilities and list learning "suggest that learning varies in relation to the primary source of lexical impairment (semantic or phonological)."

The studies discussed thus far have suggested that there are dissociable components to STM, and that phonological STM is not necessary for establishing associations between meaningful words. Rather, a semantic component of STM is able to support this process as well as the comprehension of verbal material. Phonological STM appears to have a key role in the repetition and learning of new phonological forms such as nonwords and foreign words, as well as learning of words without a concrete semantic representation.
Further evidence of a dissociation between phonological and semantic short-term memory comes from studies in our lab (R. Martin & Romani, 1994; R. Martin, Shelton, & Yaffee, 1994, R. Martin & Lesch, 1996). R. Martin and Romani (1994) studied two patients with very distinct STM deficits. Patient EA (R. Martin et al., 1994) had suffered a stroke and subsequently experienced a deficit in the short-term retention of phonological information, with a memory span of only one to three items, depending on the type of stimuli used. She showed no significant effects of recency or word length in list recall, and no effect of phonological similarity when the stimuli were presented visually. EA was able to repeat foreign words, but she could not associate and produce them in connection with a known English word in a paired associate learning paradigm (R. Martin, 1993).

Patient AB (R. Martin and Romani, 1995, R. Martin et al., 1994), who suffered a left frontal hematoma, also showed a selective deficit in auditory verbal STM, with a memory span of only two to three items. However, he demonstrated the opposite pattern of STM impairment compared to EA. He showed normal effects of phonological similarity and word length in list recall, but did not have a distinct advantage for words over nonwords, reflecting an inability to take advantage of the lexical-semantic information inherently associated with words.

EA showed very poor performance on sentence repetition tasks (R. Martin et al., 1994), being unable to repeat any sentences verbatim. AB could repeat short sentences fairly well, but was able to repeat only one long sentence correctly. R. Martin et al. (1994) suggest that in normal sentence repetition, the conceptual representation of
the sentence is integrated with the surviving phonological record to produce an accurate reconstruction of the original sentence. Patients with phonological STM deficits, such as EA, are forced to rely on the conceptual representation alone. This leads to numerous semantic errors as semantically related words may be activated and produced in place of the original word when the sentence is reconstructed. Patients with semantic deficits, such as AB, also have trouble with verbatim sentence repetition tasks because they are unable to retain the semantic information from individual words long enough to support their integration into a complete conceptual representation of the sentence. Thus, they are able to perform quite well on shorter sentences which can be accurately reconstructed by the surviving phonological record. Longer sentences are much more difficult, however, because the phonological record cannot be maintained for long utterances, and the lexical-semantic representation cannot be accessed to help reconstruct the sentence accurately. Thus, sustained activation at the phonological level is essential for verbatim repetition of sentences, and the lexical-semantic representation is helpful in reconstruction of the sentences, especially those which exceed the phonological STM capacity.

A third patient, ML, shows normal patterns of phonological effects on STM but reduced or absent semantic effects, like AB (R. Martin & Lesch, 1996). Both AB and ML are impaired at tasks such as long-term list and paired associate learning, but they do have normal long-term retention of stories, suggesting that their long-term learning is mainly impaired when they are unable to convert lexical-semantic information into higher level semantic representations (i.e.,

THE PROCESS OF LEARNING ASSOCIATIONS

The following study investigates the differential effects of impairment to these dissociable STM components on long-term learning of different types of information. To learn to associate two concepts, the phonological and semantic representations of the first concept must be linked to the phonological and semantic representations of the second. These representations must be retained in STM in order to form the connections necessary for long-term learning of the association. Figure 1 illustrates the connections used to associate two unrelated words, as in a paired associate task. As a word is heard, the phonological and semantic representations are activated. When heard in conjunction with another word, connections are formed between the two. These connections may involve mediating links through other concepts as elaborate associations are made, rather than a direct link. In either case, a connection is formed between the two unrelated concepts. Further repetitions of the association serve to strengthen the links between the representations. When two items are already associated, the pre-existing link greatly aids learning, as the connection is already formed and must only be activated and strengthened.

At test, given the initial phonological form, the person must have formed the necessary links and be able to retrieve the appropriate phonology for output. A breakdown in the learning process could occur at various points. Impaired phonological STM may prevent the formation of connections between the two phonological
Figure 1
Connections for learning two unrelated words.

Figure 1. Dotted arrows represent new links which must be formed when learning a new association between unrelated words. Solid arrows represented pre-existing links.
representations. In everyday situations, the connections between phonological representations are probably not used extensively. However, as will be discussed below, they would be very important for the learning of novel phonological forms for which there is no pre-existing semantic representation. They could also be useful in other more artificial circumstances, such as the retrieval of rhyming words. Normally, however, phonological connections are probably mediated somewhat through semantic links, as people invent semantic associations related somehow to the novel phonology to help form the connection. Thus, when the connection cannot be formed between the phonological representations, retrieval of the appropriate word would depend on the connections between the semantic representations. It would be predicted that if semantic STM capacity is preserved, the person would be able to learn pairs having pre-existing associations as well as form new links between unassociated known words. In contrast, a semantic STM deficit would preclude the formation of new connections between two semantic representations. While it would be predicted that a patient with such a deficit would be able to learn highly associated words, his performance would decrease as a function of the diminishing strength of the pre-existing associations. With no pre-existing link, he would be impaired at forming new associations because he would not be able to hold the semantic representations in memory.

The relationship between impaired phonological or semantic components of STM and long-term learning was tested by having patients learn three types of paired-associates which specifically required the formation of connections between unrelated semantic or
phonological representations, or between words having varied degrees of pre-association. The first task, designed to test the patients' abilities to learn novel semantic associations, used common words paired with unfamiliar definitions. Figure 2 depicts the connections necessary to pair a novel definition with a known word. The definition is comprised of several words, each of which has semantic and phonological representations. The subject must learn to pair that set of words to the one-word meaning which also has its own semantic and phonological representations. A patient with impaired semantic STM would have difficulty forming these new connections between the semantic representations. A patient with a phonological STM impairment, however, should still be able to form new connections between semantic representations. Connections between the phonological representations is not necessary for learning new semantic associations, but failure to establish connections to specific phonological forms could result in semantic substitutions for the target words, if the semantic representation is activated, but an alternate phonological form is selected for production.

The second task was designed to test ability to learn novel phonological associations. The stimuli were comprised of common words paired with their Spanish translations. Figure 3 illustrates the connections needed to learn novel phonology (foreign words). As a newly-encountered foreign word has no known semantic representation, the sole link to its translation is that between the phonological representations. Thus, a patient with a semantic STM impairment who can still hold phonological representations in memory should be able to form new connections in learning a foreign word.
Figure 2
Connections for learning association between a new definition and a known word.

Figure 2. Dotted arrows represent new links which must be formed when learning a new association between a novel definition and a known word. Solid arrows represented pre-existing links.
Figure 3
Connections for learning association between a foreign word (novel phonology) and its meaning.

Foreign Word

(no semantic representation)

Phonological

Phonological

Input

Output

Semantic

Figure 3. Dotted arrows represent new links which must be formed when learning a new association between novel phonology and a known word. Solid arrows represented pre-existing links.
A patient with a phonological STM deficit, however, would be unable to hold the phonological representations in memory, and would thus be unable to form new connections between them.

The final task used adjective-noun pairs having different levels of association (Postman & Keppel, 1970). As mentioned with respect to Figure 1, patients with either type of STM impairment should be able to learn word pairs having pre-existing associations, since the formation of new links is not required. However, these connections must be activated and strengthened, so it would be predicted that patients with preserved semantic STM would be best able to learn such pairs. Learning of unassociated pairs would require the retention of semantic codes in memory in order to form new connections. Evidence suggests that verbal mediators play a large role in learning paired associates of randomly paired words (Underwood, 1964). (For example, to associate the words "finger" and "tack," a subject might think about a finger which points, and that a tack has a pointed end.) A semantic STM impairment which prevents retention of these representations in memory would impair a subject's ability to create new connections between known words. In contrast, formation of new connections should still be possible despite a phonological STM impairment.

As discussed earlier, patients were selected to have good single word processing skills. However, these were assessed mainly through processes on the input side (e.g., phoneme discrimination and word comprehension). Some of the patients did display deficits on the output side, specifically in picture naming. (In traditional terminology, they were anomic.) Good comprehension paired with poor naming
suggests that the deficit in naming is due to difficulty in retrieving the phonological form from a preserved semantic representation. In Figures 1, 2, and 3, this would be represented by weakened pre-existing links going from semantics to phonology. These weakened links could impair performance on all of the tasks, because, at test, the subjects' task requires retrieving the phonological from of the target response. Even if the patient has formed requisite links at the semantic level, he or she might be unable to activate the appropriate output form to make a response. Thus, this potential confounding factor will have to be taken into account in interpreting the patients' performance.

Six patients will be presented who show different patterns of STM impairment. First, each of the main tasks used to determine their STM capacities and learning abilities will be described with data from control subjects, followed by a report of the performance of each patient on all of the tasks.

**TASK DESCRIPTIONS AND CONTROL DATA**

**Participants**

Patients having different patterns of STM impairment and age-matched controls were tested on each of the main tasks. Some patients completed additional follow-up tasks where appropriate to investigate alternative explanations for their performance. Different sets of control subjects participated in the various tasks. Overall, their ages ranged from 52 to 74, and their education ranged from high school to doctorate level. All subjects were paid for their participation.
Phonological Tasks

Phoneme Discrimination Task

The phoneme discrimination task is part of the Philadelphia Comprehension Battery (PCB; Saffran, Schwartz, Linebarger, & Bochetto, 1989). This task implements a minimal pair judgment paradigm in which two stimuli are presented auditorily and the subject must decide if they are phonologically identical or not. Performance on this task reflects ability to process speech input.

Materials

The stimuli were composed of 160 phonologically similar pairs (80 word and 80 nonword pairs). Half of the pairs were phonologically identical, and half differed by one or two phonemes in the initial, medial or final position of the stimuli. The task was divided into five blocks of 32 trials. The trials were divided evenly between word and nonword pairs and identical and non-identical pairs.

Design and Procedure

The stimuli were presented in two main conditions: no delay and filled delay\(^1\). In the no delay condition, the two stimuli were spoken aloud by the examiner at approximately one item per second. After hearing both stimuli, the subject determined whether they were the same or different and the response was recorded. In the filled delay condition, the examiner presented the initial item in the pair, then counted aloud together with the subject from 1 to 5 at a rate of one

---

\(^1\) Some subjects also completed an unfilled delay condition, which is similar to the filled delay except that, rather than counting aloud together, there was a silent five second interval between the stimuli. Data for this condition is presented in Table 1 where available, but the critical measures used for evaluating phonological processing and STM are the no delay and filled delay conditions.
number per second. After counting, the examiner presented the second item and the subject determined whether the stimuli were the same or different.

Results

Results for five age-matched control subjects are presented in Table 1. Clearly, they performed near ceiling on this task, with very little difference between the means for the no delay and filled delay conditions (99.2 vs 98.8).

Nonword Perception and Discrimination Tasks

These tasks were developed to assess the possibility that poor performance on the foreign word learning tasks might be due to impaired perception of nonwords (novel stimuli). In the repetition task, subjects are asked to repeat nonwords, while in the discrimination task they listen to a pair of nonwords and determine if they are the same or differ by one phoneme. The discrimination task has the advantage over the repetition task in that it does not require the patients to verbally reproduce the stimulus. Though the patients have not demonstrated great difficulty in word repetition, word finding and spontaneous speech is disrupted for some of them. The nonword discrimination task is more difficult than the phoneme discrimination task described above because the phoneme discrimination stimuli include both words and nonwords. Thus,
Table 1

Performance on Phonological Processing and STM Measures

<table>
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<tr>
<th></th>
<th>Controls</th>
<th>Range</th>
<th>EA</th>
<th>ML</th>
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<th>GR</th>
<th>AB</th>
<th>IG</th>
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<td><strong>Phonological Tasks</strong></td>
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<td>Phoneme Disc.</td>
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<tr>
<td>No Delay</td>
<td>99.2</td>
<td>98 - 100</td>
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<td>98</td>
<td>99</td>
<td>94</td>
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<td>99</td>
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<tr>
<td>Unfilled Delay</td>
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<td>98 - 100</td>
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<td>-1</td>
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<tr>
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<td>60 - 100</td>
<td>60</td>
<td>60</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td>50</td>
</tr>
<tr>
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<td>70 - 100</td>
<td>80</td>
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<td>90</td>
<td>60</td>
<td>80</td>
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<td>3-syl</td>
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<td>80 - 100</td>
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<td>60</td>
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<td>80</td>
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<td>4-syl</td>
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<tr>
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<td>IG</td>
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<tr>
<td>Discrimination</td>
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<td>1-syl</td>
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<td>80 - 100</td>
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<td>80 - 100</td>
<td>70</td>
<td>70</td>
<td>70</td>
<td>100</td>
<td>80</td>
<td>90</td>
</tr>
<tr>
<td>Mean (1 &amp; 2) - (3 &amp; 4)</td>
<td>94.5</td>
<td>82.5 - 100</td>
<td>85</td>
<td>87.5</td>
<td>87.5</td>
<td>97.5</td>
<td>87.5</td>
<td>92.5</td>
</tr>
<tr>
<td><strong>Rhyme Probe</strong></td>
<td>7.5</td>
<td>5 - 10</td>
<td>2.65</td>
<td>3</td>
<td>4.6(7)</td>
<td>4</td>
<td>4.6</td>
<td>3</td>
</tr>
</tbody>
</table>
subjects could use semantic information for the comparison of some of the stimuli on the phoneme discrimination task.

As repetition of multisyllable nonwords can be challenging even for controls, it was anticipated that the patients, who experience slight speech production problems, would have some difficulty with the repetition task. Gathercole and Baddeley (1989) demonstrated that nonword repetition ability is a good indicator of phonological STM capacity. Thus, patients with phonological retention deficits should be even more impaired than other patients at repeating the nonwords as a function of length, as was PV (Baddeley, Papagno, & Vallar, 1988). While these patients may be able to retain one syllable of novel phonology, their STM span will not support the retention of longer stimuli. Patients with a semantic retention deficit may also be impaired relative to controls because of mild difficulties with production, but should perform at a much higher level than patients having phonological STM deficits.

Semantic STM patients should demonstrate strong performance on the nonword discrimination task. The memory demands in this task are small (especially for the shorter nonwords) since there is no delay between the pair members, and the unfamiliar phonology does not have to be repeated without any semantic support. Again, however, patients with phonological STM deficits should have difficulty with discriminations involving the longer nonwords since the memory load increases with longer stimuli. This task is particularly important in assessing abilities of those patients with phonological STM deficits because impaired nonword perception could be offered as an alternative explanation for the dissociation in their performance on
phonological and semantic STM tasks. If the patients were not able to accurately discriminate at least the shorter nonwords of one and two syllables which do not impose a heavy memory load, then it would not be surprising that they would be particularly impaired on tasks which require the learning of novel phonological forms.

Materials

For the nonword repetition task, a list of 40 nonwords were constructed ranging from one to four syllables long, 10 at each length. For the nonword discrimination task, another set of 40 nonword pairs were constructed, also having 10 pairs at each length of one to four syllables. Half of the pairs contained identical nonwords, and half contained nonwords which differed by only one phoneme. The position of the differing phoneme was varied across words so that it occurred in beginning, middle, and end positions. The randomized position of the differing phoneme ensured that the subjects would need to attend to and maintain the entire initial stimulus in order to make an accurate discrimination. All nonwords were digitized onto a computer and played on external speakers.

Design and Procedure

For the repetition task, each nonword was played, and the subject's task was to simply repeat the nonword as accurately as possible. The items were blocked according to number of syllables, and the subject's responses were recorded on tape.

For the discrimination task, each pair of nonwords was presented and the subject's task was to decide if the two stimuli were the same or different. These were also blocked according to the
number of syllables. The subject said either "same" or "different," or pointed to the appropriate word ("same" or "different") written out.

Results

Eight age-matched controls demonstrated high performance on both of these tasks, though there was a large range for several of the item lengths (see Table 1). Interestingly, in the nonword repetition task, performance was lowest for the single syllable nonwords. One possible explanation for this pattern of performance is that the shorter nonwords have more lexical neighbors than the longer nonwords (that is, words that differ from the nonword by a single phoneme). Thus, subjects may be more likely to make lexical errors in their responses. In fact, subjects averaged 1 lexicalization error for the 1-syllable words which accounted for 57% of the errors. For the 2-syllable nonwords, subjects averaged only .25 lexicalization errors, which accounted for only 29% of the errors. There were no lexicalization errors for the 3- and 4-syllable nonwords.

The ranges for performance on the nonword discrimination task were smaller than those for the repetition task due to the easier nature of the task, as the subjects were only required to perceive and discriminate between the nonwords rather than reproduce them. The combination of these two tasks can be a useful tool in evaluating the patients' phonological processing ability. Though a patient may perform poorly on the repetition task, it is possible that input phonological processing is still intact and the low performance only reflects a peripheral production impairment. Furthermore, the repetition task seems to place a heavier demand on phonological STM. Thus, good performance on the discrimination task despite poor
performance on the repetition task would suggest intact phonological processing on the input side, but either impaired phonological STM or a peripheral production problem.

**Rhyme Probe Task**

This task combined with the category probe task (described in the semantic tasks section) compares subjects' ability to maintain phonological versus semantic information in memory. The rhyme probe task requires the retention of the sounds of a list of words for later comparison against a probe item. Patients with impaired phonological STM should be impaired on this task relative to the category probe task which requires maintenance of semantic information of the list items.

**Materials**

The rhyme probe task consists of words in several different rime groups (e.g., /æt/ as in "cat" and "mat"; /ʌt/ as in "boot" and "loot"). Blocked lists of 1 to 10 words having all different rimes are presented followed by a probe word. Half of the probe words rhyme with one of the list items, and half do not. For lists which do contain an item which rhymes with the probe, the rhyming item appears in each list position an equal number of times. The lists are recorded on a cassette tape with a 1 s pause between each item and a 2 s pause between the final list item and the probe word.

**Design and Procedure**

The subject listened to each list and responded "Yes" or "No" whether the probe item rhymed with any of the list items. After all lists of a specific length were finished, the percent of correct responses was calculated for that list length. When the percent correct dropped
below 75%, testing was discontinued and span was determined as the estimated point at which performance equaled 75%.

Results

Six age-matched control subjects were tested on the rhyme task (see Table 1). The mean rhyme probe span was 7.5 (range = 5 - 10). The results of the rhyme probe task are most meaningful, however, when compared with performance on the similar category probe task, described below.

Semantic Tasks

Peabody Picture Vocabulary Test

The PPVT (PPVT; Dunn & Dunn, 1981) is a standardized picture matching task which was used because it allows for testing semantic processing without production.

Relatedness judgment task

This task was designed to determine whether some patients’ difficulty in learning novel semantic information compared to phonological information could be attributed to an inability to understand the words used to convey the information. It tested the patients’ ability to evaluate relationships between objects and make fine discriminations between word meanings.

The task requires subjects to make semantic judgments about the relationships between word meanings. Two versions of this task were administered, a two-choice and a three-choice version. In the two-choice version, the subject had to choose which item out of two was most closely related to the third. The three-choice version required the subject to choose which two out of three were most closely related to each other. This three-choice version places greater
demands on STM because three relationships among the words must be held in memory and considered in order to make a decision, rather than two. Due to these demands on STM, patients with semantic STM deficits should have greater difficulty with the three-choice than the two-choice version, though both tap the same knowledge. Patients with relatively preserved semantic STM and impaired phonological STM should demonstrate no greater difficulty on the three-choice task relative to the two-choice task, as they should be able to hold the words and their relationships in STM. Thus, a dissociation in performance on these two versions would suggest impaired semantic STM but preserved semantic processing.

Materials

The materials were constructed using the content words from the paired associate learning task (which will be described below). For each of the target words and content words contained in the pairs (composed of a short definition and the target word), a strongly related and a weakly related distractor were collected, resulting in 86 triads.

Design and Procedure

In both versions of this task, each content word was presented in a triad with the strongly related word and weakly related distractor. In the two-choice version, the target word appeared at the top of the screen, with the two choices presented below. The subject was instructed to choose which one of the two bottom words was most closely related in meaning to the top target word (i.e., for the target "talon," choose between "beak" and "claw"). The experimenter read each word out loud for the patients to ensure that they were all
properly perceived. The subject either spoke or pointed to the word which was most closely related to indicate his or her response.

In the three-choice version of the task, the target and the two choices were presented in a row in random order. The subject was instructed to choose which two of the three words were most closely related in meaning.

Results

Six age-matched controls were tested and performed well on the two-choice version, though no one achieved a perfect score. The mean was 95% with a range of 92% to 99% (see Table 2). On the three-choice version, controls' performance decreased slightly, obtaining an average of 92.7%, with a range of 86% to 98%. The fact that no one achieved a perfect score on either version reflects the difficulty of the task due to the subtle discriminations required for many of the test items (e.g., convict, inmate and thief).

Single Word-Single Picture Matching Task

This task taps subjects' semantic processing capacity without requiring production and with minimal demands on STM.

Materials

The task consists of 54 questions in the form of "Is this a _____?" Each question is asked in relation to four different pictures: phonologically related, semantically related, unrelated, or one which matched the picture name.

Design and Procedure

In each of four sessions, the subject is asked 54 questions, each in relation to a picture, and decides whether the picture matches the word in question. The same 54 questions are asked in each session,
Table 2

Performance on Semantic Processing and STM Measures

<table>
<thead>
<tr>
<th>Semantic Tasks</th>
<th>Controls</th>
<th>Range</th>
<th>EA</th>
<th>ML</th>
<th>AK</th>
<th>GR</th>
<th>AB</th>
<th>IG</th>
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<td>100</td>
<td>s.d.=15</td>
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<td>113</td>
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<td>117</td>
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<td>98</td>
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<td>92 - 99</td>
<td>93</td>
<td>97</td>
<td>92</td>
<td>94</td>
<td>63</td>
<td>91</td>
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<tr>
<td>Three-choice Relatedness</td>
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<td>86 - 98</td>
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<td>92</td>
<td>78</td>
<td>83</td>
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<td>78</td>
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<td>14</td>
<td>11</td>
<td>8</td>
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<td>96 - 99</td>
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<td>1</td>
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<td>1</td>
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<td>EA</td>
<td>ML</td>
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<td>65</td>
<td>100</td>
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<td>2.4</td>
<td>2.4</td>
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</table>
but paired with different pictures. Also, each session contains an equal number of phonologically related (pen - hen), semantically related (pen - pencil), unrelated (pen - toilet), and matching (pen - pen) pictures.

Results

The average score of the six control subjects tested on the single word-single picture matching task was 98, with a range of 96 to 99 (see Table 2). They made an average of two semantic errors, one phonological error, and two incorrect rejections of a correct match. No one committed any errors with unrelated distractors.

Category Probe Task

The category probe task taps the subjects' ability to maintain semantic information about list items in STM. Patients with a semantic STM deficit should be impaired on this task relative to the rhyme probe task which requires the maintenance of phonological information of list items.

Materials

The category probe task consists of 24 words in each of 9 different categories (e.g., flowers, clothing, and animals) (Battig & Montague, 1969). There are lists of lengths 1 to 7, and each list is followed by a probe word, half of which are, and half of which are not, a member of the same category as one of the list items. For lists which do contain an item in the same category as the probe, the same-category item appears in each list position an equal number of times. The lists are recorded on a cassette tape with a 1 s pause between each item and a 2 s pause between the final list item and the probe word.
Design and Procedure

The subject listened to each list and responded "Yes" or "No" whether any one of the list items was in the same category as the probe item. After all lists of a specific length were finished, the percent of correct responses was calculated for that list length. When the percent correct dropped below 75%, testing was discontinued and span was determined as the estimated point at which performance equaled 75%.

Results

The same six age-matched control subjects who completed the rhyme probe task were tested on the category probe task (see Table 2). The mean category probe span was 6.1 (range = 5 - 7). Thus, on average, the controls performed at a higher level on the rhyme than category probe task with a mean advantage of 1.4 items. Only one of the controls performed better on the category than the rhyme probe (5.8 vs. 5.0). This control subject, however, had the lowest overall performance of all the subjects. The remainder of the subjects showed a rhyme versus category probe difference that ranged from 0.7 to 3.0.

Attribute Judgment Task

In this task, the subject is presented with a series of questions, each of which asks which of two items matches a given adjective, such as "Which is small, a flea or a house?" Though seemingly trivially easy, these questions can be difficult for patients having semantic STM impairments because they may be unable to hold the adjective in mind and compare it with each of the two alternatives at once. Patients with a semantic STM deficit should perform better on the alternate versions of the task which have reduced memory loads.
Materials

The task is composed of 40 attribute judgment questions. In the reduced memory load version of this task, there are 84 questions and the format of the questions is changed such that the subject does not need to hold the attribute in memory while comparing the two alternatives (e.g., "Is a flea small?"). For the visual version, the original questions are presented on paper.

Design and Procedure

The experimenter asks each question to the subject and the subject makes his or her response. The reduced memory load questions are administered by the same procedure. The visual version is presented on paper and the subject reads each question and marks his or her response.

Results

Controls perform at ceiling on the original version of this task (see Table 2). All controls scored 100%, except for one who scored 97%.

Word/Nonword Span Tasks

This task tests subjects' short-term retention of semantic information by comparison of STM abilities for words and nonwords.

Materials

Ten low frequency, 1-syllable words were used for the word lists. The nonwords were composed using the same phonemes as the words but reordered to form nonwords.

Design and Procedure

Each of the items appeared one per second on a computer screen out of the subject's view, and the experimenter read each word aloud to the subject. After the list presentation, the subject responded by
pointing to the items printed in random order on paper. There were 10 trials for each list length, beginning with two-item lists\textsuperscript{2}. Repeated sampling was used from the same set of 10 words or nonwords for each list. Testing was continued until the subject obtained less than 50\% of the lists correct. Span was determined as the estimated point at which the subject obtained 50\% of the lists correct\textsuperscript{3}.

**Results**

Normal subjects show an advantage for words over nonwords (Brener, 1940; Hulme, Maughan & Brown, 1991), which can be attributed to lexical-semantic information in the word lists which aids retrieval. Insofar as a patient has a deficit in the short-term retention of semantic information, we would expect to find little advantage for retention of words over nonwords.

**Long-term Learning Tasks**

**Paired Associate Tasks**

Paired associate learning tasks were used to compare the patients' ability to learn novel semantic information with their ability to learn novel phonological information. Prior research has suggested that short-term phonological retention is essential for learning novel phonological information but not semantically meaningful material, as illustrated by PV's (Baddeley, Papagno, & Vallar, 1988) inability to learn paired associates consisting of a known word and a foreign word

\textsuperscript{2}If a patient scored under 50\% on two-item, lists, s/he was then tested on one item lists.

\textsuperscript{3}This same procedure was used for testing the phonological similarity effect, in which 10 phonologically similar and 10 dissimilar words were used to test ability to retain phonological information. Also, for some of the patients data is available for visual administration of these tasks, in which the subject saw each item appear on the computer screen rather than listening to the experimenter. (See Appendix A).
and her normal ability to learn pairs consisting of two meaningful items. Therefore it was predicted that patients with phonological STM deficits would be better able to learn pairs consisting of novel semantic information than those containing novel phonology. In contrast, patients with semantic retention deficits should be better able to learn the pairs consisting of novel phonology (containing a novel word) than those consisting of familiar words but containing a novel semantic association. Further, for patients with a semantic STM deficit, their performance on tasks requiring the learning of associations between known words should vary as a function of the amount of pre-existing semantic association between the two stimuli. It was also predicted that level of pre-existing semantic association would have less effect on patients with phonological STM deficits because they should be able to construct and retain novel semantic associations.

**Materials**

**Definitions.** For the novel semantic learning task, subjects had to learn unfamiliar definitions for known words. Fifty common words having unfamiliar definitions were collected (e.g., ounce - snow leopard). The words and definitions were presented to 33 age-matched controls (mean age = 59.8). The subjects were instructed to rate the familiarity of the word and its meaning on a 4-point scale (1 = very unfamiliar and 4 = very familiar). The 32 least familiar pairs were chosen, having a mean familiarity rating of less than 2.

**Foreign words.** The stimuli for the new phonological learning task consisted of common words paired with their Spanish translations, which were easily pronounceable in English (e.g., arrow -
flecha). Twenty-one age-matched controls (mean age = 59.2) rated the familiarity of the 50 Spanish words presented without the English equivalent on the same 4-point scale. The 32 least familiar pairs were chosen, having a mean familiarity rating of less than 1.5. Each block of eight pairs contained six 2-syllable and two 3-syllable Spanish words.

**Adjective-noun pairs varying in degree of prior association.** The final task used 16 adjective-noun pairs at each of three levels of pre-existing association (Postman & Keppel, 1970): high association (e.g., corrupt - politician), low association (e.g., rich - flavor), or unassociated (e.g., rude - basket).

The experiment was run using the PsyScope program (Cohen, MacWhinney, Flatt, & Provost, 1993) on a Macintosh PC. All of stimuli were presented auditorily. The stimuli were digitized and presented under computer control over external speakers.

**Design and Procedure**

The blocks in each task were composed of eight pairs of associates. There were four blocks each of the foreign and definition pairs, and two blocks of the adjective-noun pairs at each level of association. Each trial in a block consisted first of a study phase in which the eight pairs were auditorily presented in random order with a 2 s pause between each pair. After the study phase, there was a 5 s pause followed by the test phase, in which the initial item of each pair was presented auditorily and the subject tried to recall the corresponding second item of the pair. This process was repeated until all eight pairs were correctly recalled twice in a row or until eight trials were completed. While the pairs were presented in random order at both study and test, the items within each pair were
always presented in the same order. Thus, the definition, the Spanish word, and the adjective were always presented first in the pair for each of the respective tasks. The initial item of each pair always served as the probe and the second item was the target.

Results

Eight age-matched control subjects were tested and all performed at a very high level on each of the paired-associate tasks. The controls performed significantly better on the definition task than the foreign word task (see Figure 4) as measured using two criteria. First, subjects on average recalled a larger total number correct per block in the definition task (Mean=59.2) than in the foreign word task (Mean=55), $t(7)=4.05$, $p=.005$, and second, they needed fewer trials to reach criterion in the definition task (3.9) than in the foreign (4.9), $t(7)=5.48$, $p=.001$.

Individual analyses were conducted for each subject's results to determine if all subjects demonstrated higher performance on the definitions than the foreign words. Four of the subjects made significantly more correct responses per block on the definitions than on the foreign words at the .05 level. Three of the subjects showed performance in that direction, though it did not reach significance. Only one subject did not show that effect, but she had the highest performance of all the subjects. Further, her better performance on foreign words than definitions did not approach significance. She made only slightly more correct responses per block on the foreign words (Mean=60.8) than the definitions (Mean=60.3), $t(7)=.607$, $p=.56$. Thus, virtually every control subject performed better on the definitions than on the foreign words.
Figure 4
Controls' Performance on Definition and Foreign Pairs

On the adjective-noun pairs with the three levels of association, controls performed significantly better on the high and low associated pairs than on the unassociated pairs (see Figure 5). They recalled a larger total number of items per block of the high associates (Mean=62.4) than the unassociated (Mean=52.4), $t(7)=9.06$, $p<.01$, and they needed fewer trials to reach criterion in the high associates (2.9) than in the unassociated pairs (5.7), $t(7)=9.63$, $p<.01$. Comparing the low associated and the unassociated pairs, subjects
also recalled a larger total number of items per block of the low associates (Mean=61.3) than the unassociated (Mean=52.4), \( t(7) = 8.04, p < .01 \), and needed fewer trials to reach criterion in the low associates (3.2) than in the unassociated (5.7), \( t(7) = 8.77, p < .01 \). There was no significant difference between high and low associated pairs on either measure. Individual analysis of each subject's average number of correct responses per trial revealed that all subjects showed effects in the same direction. No subject demonstrated a significant difference between performance on the high and low associated pairs, and all subjects performed worse on the unassociated pairs than on the high and low pairs. However, this difference was significant at the .05 level in planned pairwise comparisons for only five of the subjects, because the others performed near ceiling.
Recognition Paired Associate Tasks

For those patients who were unable to learn any of the types of paired-associates, a recognition paired associate task was administered. By modifying the paired associate paradigm, it could be possible to demonstrate learning by these patients. Even though they might perform at a severely reduced level, they should still be better able to learn the type of information (semantic vs. phonological) which does not rely on the relatively more impaired component of their STM.
In our paired associate tasks described previously, the "study-test presentation," or "blocked," method (Kintsch, 1977) was used. In that version, lists of pairs are presented to the subject, followed by the test phase, in which the first item of each pair is presented in random order and the subject's task is to produce its counterpart. In our experiment, all of the pairs were presented first for study, followed by test, without feedback.

Studies of normal subjects have demonstrated that some methods of presenting paired associates result in faster learning than others (Kintsch, 1977). One such method is the anticipation paradigm, in which there is not a blocked study or test phase. Rather, the subject is given the opportunity to study each item immediately after test. In the first trial, each pair is presented. In later trials, however, only the initial item is presented for 2 s, and the subject attempts to recall the associate before it appears on the screen. After the time has elapsed, the correct answer appears and remains on the screen for an additional 2 s to be studied. This process is repeated a number of times until a specified criterion is met.

In some respects, this anticipation method may not be particularly advantageous for use with aphasic patients. Many patients have very long word retrieval times in spontaneous speech, and would have trouble producing the appropriate response within a fixed time interval. The main advantage of the anticipation method, however, is the immediate feedback given to subjects after each trial. The recognition task is a variation of the anticipation method which gives immediate feedback to the subject after each response. The recognition format was used to circumvent the patients' output
problems. One other difference between this format and the traditional anticipation method is that the study and test phases were still blocked and there was no time limit imposed for the responses. It was predicted that the recognition format and immediate feedback would help to elevate the patients' performance to a level at which it would be possible to distinguish between their semantic and phonological learning ability.

Participants

Patients who were unable to learn the paired-associates in the original paradigm, as well as six age-matched control subjects were tested.

Design and Procedure

The blocks in each task were composed of eight associated pairs. There were four blocks of the definitions and four blocks of the foreign pairs. Each trial in a block consisted first of a study phase in which the eight pairs were auditorily presented in random order with a 2 s pause between each pair. After the study phase, there was a 5 s pause followed by the test phase.

In the test phase, the initial item of each pair was presented auditorily, and three response choices were presented visually on the screen. The subject's task was to recognize the corresponding second member of the pair. The three choices included the correct target, a distractor randomly chosen from the other targets within the list, and an extra-list distractor chosen from a random list of words comparable in length and grammatical class to the targets. The subject indicated his or her response verbally or by pointing. After the subject's response, the correct answer appeared on the screen, thus providing
feedback to the subject. This process was repeated until all eight pairs were correctly recognized twice in a row or until eight trials.

Results

As might be expected, the age-matched controls performed better on this task (see Figure 6) than on the original recall version in terms of their level of percent correct on the first few trials. The difference between the average number of correct responses per block was not significant, however, as the controls performed near ceiling on the original version. As in the recall version, subjects were better on the recognition task with the definitions than the foreign word pairs, though this difference was not significant with respect to average correct number of responses per block, $t = 2.1$, $p = .09$. However, they did need significantly fewer trials to reach criterion for the definitions than the foreign words ($2.5$ vs $3.3$), $t = 3.5$, $p = .02$. 
PATIENTS' PERFORMANCE ON BACKGROUND AND LEARNING TASKS

Six patients are reported who show varying patterns of STM impairment. Background information on their performance on auditory and visual memory span tasks manipulating phonological similarity and lexical status among list items is presented in Appendix A. Appendix B contains background information on two naming tasks,
the Boston Naming Test (BNT; Kaplan, Goodglass, & Weintraub, 1976), and the Philadelphia Naming Task (PNT). Data will be presented for each patient on a case-by-case basis, followed by a discussion comparing performance across patients.

Assessment of Processing and STM Abilities

For each patient, their phonological and semantic processing abilities were evaluated relative to controls. Phonological processing ability was measured by performance on four main tasks: the immediate phoneme discrimination task, the average of nonword repetition of 1- and 2-syllable nonwords, the average of nonword discrimination of 1- and 2-syllable nonwords, and list length 1 of the rhyme probe task. For each of these tasks it was determined whether the patient scored within the range of controls. These tasks were chosen because they tap phonological processing with minimal demands on STM.

Semantic processing ability was examined in terms of three main tasks: the PPVT, the 2-choice relatedness judgment task, and the single word-single picture matching task. These tasks were chosen because they tap semantic processing with minimal demands on STM, as well as having the advantage that they do not require speech production which is disrupted in some patients.

In order to quantify the patients' relative phonological and semantic STM abilities, two composite scores were calculated which combined measures of performance on different STM tasks. For each measure included in the composite score, the z-score for each patient was calculated relative to the other patients. Their composite scores were determined as the sum of their z-scores for each measure.
The composite phonological STM score included performance on the following measures: 1) The difference between performance on the no delay and filled delay conditions of the phoneme discrimination task. Both of these conditions tap phonological processing to the same extent. The only difference is that the filled delay condition requires the retention of novel phonology over time while rehearsal is prevented. 2) The difference between the average of 1- and 2-syllable nonword repetition and the average of 3- and 4-syllable nonword repetition. Both of these require retention and production of novel phonology. However 3- and 4-syllable nonword repetition requires the retention of longer phonological forms, which poses larger demands on phonological STM. 3) The difference between the average of 1- and 2-syllable nonword discrimination and the average of 3- and 4-syllable nonword discrimination. Like the nonword repetition measure, the discrimination of 3- and 4-syllable stimuli requires the maintenance of longer phonological forms, which constitutes a greater load for phonological STM. 4) Performance on the rhyme probe task. Estimated span on this task reflects the amount of phonological information which can be held in STM for later comparison to a probe item.

The composite semantic STM score was determined by performance on the following measures: 1) The category probe task. Scores on this task reflect the amount of specifically semantic information which can be held in STM for later comparison to a probe item. 2) The difference between scores on the 3-choice and 2-choice relatedness judgment tasks. Both of these tasks tap knowledge of the same material, but the 3-choice task imposes a greater memory load as three relationships among the items must be maintained and
considered instead of two. 3) The attribute judgment task. This task is sensitive to semantic STM deficits because it requires the retention of an unintegrated adjective for comparison to two nouns, all of which must be held in STM to make an accurate response. 4) The difference between span for words and for nonwords. Smaller raw scores on this measure reflect a greater semantic STM impairment because it suggests that the subject is not benefiting from the added semantic information inherent in words and absent in nonwords.

Patient EA

EA is a 66-year-old college-educated woman who suffered a left hemisphere stroke in 1975, involving the left temporal and parietal lobes, and including the primary auditory cortex, Wernicke's area, and the superior and inferior parietal lobules. She demonstrates good comprehension and fluent speech, with very occasional phonological paraphasias in multi-syllable words. She has a STM deficit in the retention of phonological information.

Phonological processing and STM

EA, who has been reported extensively (Friedrich, Glenn, & Marin, 1984; R. Martin & Romani, 1994; R. Martin, Shelton, & Yaffee, 1994), demonstrates good phonological processing on some tasks, though she performed below the range of controls on two of the four critical phonological processing tasks (see Tables 1 and 3). She performed within the control range on phoneme discrimination with no delay (98%) and on nonword discrimination of 1- and 2-syllable nonwords. She performed below the range of controls, however, on the average of 1- and 2-syllable nonword repetition, though she was
Table 3

Assessment of Patients' Phonological Processing Abilities Relative to Controls

<table>
<thead>
<tr>
<th>Measure</th>
<th>EA</th>
<th>ML</th>
<th>AK</th>
<th>GR</th>
<th>AB</th>
<th>IG</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Delay Phoneme Discrimination</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Nonword Repetition</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average 1- and 2-syllable</td>
<td>+</td>
<td>-</td>
<td></td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Nonword Discrimination</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average 1- and 2-syllable plus</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Rhyme Probe</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>List length 1*</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

*All controls scored 100% on length 1 of the rhyme probe. Though four of the patients did not score at the level of controls, they all scored 95%, only missing one item.
within the range of controls for each length individually. She also performed below the range of controls on the one-item lists of the rhyme probe task, though she missed only one item. Thus, she has at most a very mild impairment of phonological processing. More likely is the possibility that her phonological STM deficit (discussed below) is so severe that it is sensitive to even the very slight demands on STM of the repetition and rhyme probe tasks. The repetition task requires maintenance and production of the entire phonological form, whereas discrimination tasks can often be accomplished even if the entire phonological form is not retained. All of EA's failures to recognize differences between two stimuli in the nonword discrimination task occurred in trials where the differing phoneme occupied the final position of the word (or was located in the final syllable for one of the 4-syllable nonwords). This suggests that she often did not retain the entire novel phonological form and would explain her performance below the range of controls on the nonword repetition task. All of her errors on the 1-syllable nonword repetitions occurred in the medial or final phonemes, and all errors in the 2-syllable nonwords occurred in the final phoneme. This would also explain her performance outside the range of controls on the rhyme probe task, which requires discriminations based solely on the endings of words. It is unclear, however, why she would retain the beginnings rather than the endings of the stimuli.

EA performs very poorly on each of the tests requiring phonological retention (see Table 4). With an unfilled delay between the two stimuli in the phoneme discrimination task, her performance remained high, at 97%. However, with a filled delay, her performance
<table>
<thead>
<tr>
<th>Measure</th>
<th>EA</th>
<th>ML</th>
<th>AK</th>
<th>QR</th>
<th>AB</th>
<th>IG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immediate - Filled</td>
<td>-1.27</td>
<td>.70</td>
<td>1.44</td>
<td>-1.03</td>
<td>-.53</td>
<td></td>
</tr>
<tr>
<td>Phoneme Discrimination</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nonword Repetition</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1&amp;2 syllable - 3&amp;4 syllable</td>
<td>-1.62</td>
<td>-.1</td>
<td>1.72</td>
<td>-.4</td>
<td>-.1</td>
<td>.51</td>
</tr>
<tr>
<td>Nonword Discrimination</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1&amp;2 syllable - 3&amp;4 syllable</td>
<td>.19</td>
<td>.93</td>
<td>.93</td>
<td>1.3</td>
<td>1.3</td>
<td>-93</td>
</tr>
<tr>
<td>Rhyme Probe</td>
<td>-1.25</td>
<td>-.81</td>
<td>1.21</td>
<td>1.21</td>
<td>1.21</td>
<td>-81</td>
</tr>
<tr>
<td>Total</td>
<td>-3.95</td>
<td>-1.14</td>
<td>2.70</td>
<td>2.79</td>
<td>1.38</td>
<td>-1.76</td>
</tr>
</tbody>
</table>
dropped to 87.5% correct, indicating difficulty maintaining a phonological representation over time without continuous rehearsal to refresh the phonological representation. EA showed a very large discrepancy between her performance on the nonword repetition task for short (1- and 2-syllable nonwords) and long (3- and 4-syllable nonwords). Hers was the largest difference among all of the patients, and she was unable to correctly repeat any of the 4-syllable nonwords. EA does not have a production impairment, as evidenced by her fluent conversational speech, very rare occurrences of phonemic paraphasias, and normal performance on a narrative speech production task, which provides a quantitative assessment of aphasic speech production (Saffran, Berndt & Schwartz, 1989). She also does not have a phonological perception deficit, as indicated by her high performance on phoneme discrimination tasks with no delay. Thus, her performance appears to reflect an inability to retain the phonological record of relatively long novel stimuli in STM. The difference of her performance on the nonword discrimination task between short and long nonwords was not as large, but there was little variability on this measure for any of the patients. EA was impaired in both the rhyme and category probe tasks as compared to controls (see Tables 1 and 2). Importantly, however, she performed better on the category probe task (span = 2.82) than the rhyme probe task (span = 2.65), the reverse of the pattern for controls, reflecting her greater ability to retain semantic than phonological information. Martin, Shelton and Yaffee (1994) provide further evidence of impaired phonological STM capacity with EA's performance on span tasks. She demonstrates lack of a word length effect on span, and the
phonological similarity effect she demonstrates in the auditory modality (2.83 for dissimilar vs. 2 for similar) basically disappears in the visual modality (2.7 for dissimilar vs 2.6 for similar).

**Semantic processing and STM**

EA maintains very good semantic processing and relatively intact semantic STM abilities (see Tables 2 and 5). EA demonstrates semantic processing abilities within the range of controls on each of the critical tasks. She also performs within the range of controls on the two naming tasks (see Appendix B).

Her semantic STM capacity also appears well-preserved, as she obtained a positive z-score on each of the critical STM tasks and had the highest composite semantic STM score of all the patients. Her better performance on the category probe task than the rhyme probe task, which is in the opposite direction of normal controls' performance, suggests more preserved semantic STM capacity than phonological STM capacity.

Her performance did not decrease with the three-choice relatedness judgments; in fact, it actually increased slightly. She also scored 100% on the attribute judgment task, demonstrating no difficulty in maintaining several semantic representations in memory at once. Finally, she shows an effect of lexicality on memory span, indicating a benefit from semantic information available in word lists.

**Composite STM scores**

EA obtained the smallest, negative phonological STM composite score (See Table 4), combined with largest, positive semantic STM composite score (see Table 6), illustrating a large dissociation between
Table 5

Assessment of Patients' Semantic Processing Abilities Relative to Controls

<table>
<thead>
<tr>
<th>Measure</th>
<th>EA</th>
<th>ML</th>
<th>AK</th>
<th>GR</th>
<th>AB</th>
<th>IG</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPVT</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>2-choice Relatedness Judgment</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Single Word-Picture Matching</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Measure</td>
<td>EA</td>
<td>ML</td>
<td>AK</td>
<td>GR</td>
<td>AB</td>
<td>IG</td>
</tr>
<tr>
<td>-------------------------</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>Category Probe</td>
<td>.58</td>
<td>-.93</td>
<td>1.93</td>
<td>-.33</td>
<td>-.33</td>
<td>-.93</td>
</tr>
<tr>
<td>3-choice - 2-choice</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relatedness Judgment</td>
<td>1.88</td>
<td>.75</td>
<td>-.94</td>
<td>-.38</td>
<td>-.56</td>
<td>-.75</td>
</tr>
<tr>
<td>Attribute Judgment</td>
<td>.81</td>
<td>-.97</td>
<td>.81</td>
<td>.3</td>
<td>-1.74</td>
<td>.81</td>
</tr>
<tr>
<td>Word - Nonword</td>
<td>1.61</td>
<td>-.62</td>
<td>.12</td>
<td>.87</td>
<td>-.62</td>
<td>-1.36</td>
</tr>
<tr>
<td>Total</td>
<td>4.88</td>
<td>-1.77</td>
<td>1.92</td>
<td>.46</td>
<td>-3.25</td>
<td>-2.23</td>
</tr>
</tbody>
</table>
the two capacities. She is the only patient to demonstrate this pattern of better semantic than phonological STM (see Appendix C).

**Long-Term Learning**

As EA retains good semantic processing and STM, coupled with good phonological processing but very poor phonological STM, it was predicted that she would show stronger performance on tasks requiring the acquisition of novel semantic information relative to those requiring the acquisition of novel phonology. Though impaired relative to controls on both types of paired associates, EA performed significantly better on the definitions than on the foreign word pairs (see Figure 7), as measured by average number of correct responses per trial, $t(7) = 9.33, p < .0005$. She never averaged much more than one correct response per trial on the foreign word pairs. Interestingly, some of EA's errors in both types of pairs were semantic substitutions for the target word. For example, the correct response to "an old horse" was "rip," but she consistently responded "tear." Other examples were her responses of "yell" for "shout," or "a large nail" for "spike." She made this type of error more often on the definition pairs than the foreign pairs, indicating she was able to activate the semantic representation of the target word more often on the semantic learning task than the phonological task.
Because of her strong semantic STM capacity, it was predicted that EA would perform at a level similar to controls at all levels of association between the adjective-noun pairs. In fact, however, she performed near the level of controls only on the highly associated pairs (see Figure 8). Her performance decreased significantly with the pairs having low association, $t=5.66$, $p=.001$, but she still demonstrated some ability to learn the associations. Surprisingly, EA was not able to learn the unassociated pairs to any appreciable degree. Most of her
errors, especially on the unassociated pairs and the foreign word pairs were failures to respond.

Figure 8
Patient EA's Performance on High, Low and Unassociated Pairs

Discussion
As predicted, EA demonstrated greater ability to learn the new definitions in contrast to the foreign words. Her phonological STM deficit greatly reduced her ability to learn the novel phonology contained in the foreign words. Her high performance on phoneme
discrimination task with no delay and the nonword discrimination task (at least for the shorter stimuli with smaller STM demands) rules out a perceptual deficit as an explanation for her pattern of performance.

One may wonder why EA was able to learn any of the foreign pairs at all, considering that patient PV (Baddeley, Papagno & Vallar, 1988), who had a similar type of deficit as EA, never made any correct responses on foreign word paired associates. However, PV had to produce the foreign word in response to a known word, which requires maintenance and production of the entire novel phonological form. EA only had to produce a known word in response to the foreign stimulus. This task could be accomplished even if the entire novel phonological form was not learned. Only enough phonology needs to be recognized to distinguish between the different foreign stimuli. Indeed, her performance on the repetition and discrimination tasks suggests that she does not retain the entire novel phonological form. Thus, if EA had been required to produce the foreign word like PV, she likely would not have made any correct responses either.

Semantic errors which EA often made in her responses are in line with her proposed phonological deficit with relatively intact semantic abilities. These errors suggest that she retains some semantic representation of the target, but substitutes a related word since the phonological representation which would distinguish between the target and related words is lost. Other patients with semantic rather than phonological STM deficits, who will be discussed below, made very few such errors.

Contrary to predictions, EA showed a large effect of degree of association in learning of the adjective-noun pairs, with almost no
ability to learn the unassociated pairs. Discussion of the associated pairs learning and possible explanations for her performance will be deferred until the results of all the patients have been presented.

Patient ML

ML is a 55-year-old man who suffered a left hemisphere CVA in 1990. CT scan indicated an infarction involving the left frontal and parietal operculum, with atrophy in the left temporal operculum and mild diffuse atrophy. He completed two years of college and had been employed as a draftsman. ML demonstrates good comprehension and single word processing. His speech is halting and characterized by reduced phrase length. He exhibits a STM impairment for lexical-semantic information.

Phonological processing and STM

ML demonstrated a normal level of performance on all the phonological processing tasks except for the rhyme probe task where he made one error on the one-item lists. Evidence for preserved phonological STM varied substantially across tasks, however (see Table 1). On the phoneme discrimination task, he obtained 98% correct with no delay, and was hardly affected by either an unfilled delay (98% correct) or a filled delay (96%). On the nonword repetition task, he was within the range of controls for the 1- and 2-syllable nonwords, but like patient EA, he was outside their range for the 3- and 4-syllable nonwords. However, his overall level of performance on nonword repetition was substantially better than hers, and the difference between his repetition of the short (1- and 2-syllable) nonwords and the long (3- and 4-syllable) nonwords was substantially
smaller than hers (30% for ML vs. 55% for EA). On the nonword discrimination task, his performance was only slightly better than EA's and his difference between discrimination of the short and long nonwords was actually larger than hers. However, there was little variation in patients' overall performance on this task, nor in the difference between performance on the short and long nonwords. On the rhyme probe task, he performed slightly better than she did. Other evidence from prior studies also indicates a mixed picture with regard to phonological STM. He exhibits a phonological similarity effect and word length effect for auditorily presented lists, but for visually presented lists he did not show a phonological similarity effect. ML's composite phonological STM score (see Table 4) reflects this mixed picture as his score is below the mean for the patients tested here, but better than that for patient EA.

Semantic processing and STM

ML retains very good semantic processing ability (see Tables 2 and 5), scoring above the mean of control subjects on each of the semantic processing tasks. Further evidence of his good semantic processing abilities was his high scores on naming tasks (BNT and PNT; see Appendix B).

When a memory load is introduced in semantic processing, however, ML's performance decreases substantially. He performed very poorly on the category probe task (1.8), equal to the worst of the patients. He showed a drop in performance on the three-choice relatedness task (92%) compared to the two-choice version due to the increased STM demands, but was still within the range of controls. On the attribute judgment task, ML performed quite poorly at 65%. On the
reduced memory load version, his performance increased substantially to 88%, and he scored 100% when the original questions were administered visually. This increase suggests that it is the STM load rather than any type of semantic processing deficit which accounts for his poor performance on some semantic tasks. Finally, he derives very little mnemonic benefit from semantic information inherent in words, as illustrated by a greatly reduced lexicality effect on span (2.3 words vs. 2.2 nonwords).

**Composite scores**

Both semantic and phonological STM composite scores were negative for ML (see Tables 4 and 6), suggesting that he is impaired on both measures relative to the other patients. Of particular relevance to the present study is that his semantic STM impairment is worse than his phonological, the pattern opposite that demonstrated by EA (see Appendix C).

**Long-Term Learning**

Considering that ML's phonological STM abilities were somewhat better preserved than his phonological STM abilities, it was predicted that he would be better able to learn pairs containing novel phonological forms than those having novel semantic information. In line with these predictions, ML performed quite poorly in the definition paired associate task, showing very little learning across trials. In fact, he never averaged more than three correct responses per trial. On the foreign words, however, he demonstrated a definite learning curve, and in one block he even recalled all eight items. Though his performance was significantly lower than controls in both conditions, he performed significantly better in the foreign condition.
than in the definition condition (see Figure 9), as measured by average number of correct responses per trial, \( t(7) = 3.56, p = .009 \). This effect is in the opposite direction from controls who performed significantly better on the definition task than on the foreign task.

Figure 9

Patient ML's Performance on Definition and Foreign Pairs

![Graph showing performance of Patient ML](image)

Because of ML's impaired semantic STM capacity, it was predicted that level of association within the adjective-noun pairs would have a large effect on his performance and he would be unable to learn the unassociated pairs which provide no pre-existing semantic
support to aid in recall. In fact, however, ML performed at or near the range of control subjects on the high and low associated pairs, reaching criterion in all of the blocks. Though performing slightly better on the low than high associated pairs, there was no significant difference between his performance on the two types with respect to average number of correct responses per trial, $t = 1.99$, $p = .09$. His performance on the unassociated pairs, however, was well below that of controls (see Figure 10), but he did show some learning. His level of learning for the unassociated pairs was quite similar to that on the definition pairs. Many of his incorrect responses for all the types of pairs were target words from the block, but paired with the incorrect stimulus.

Discussion

ML's superior performance on the foreign compared to the definition pairs suggests that just as phonological STM deficits impair patients' learning of novel phonology (e.g., for patient EA), semantic STM deficits impair the learning of novel meanings. His performance on the associated pairs which will be discussed below, was better than predicted.
Patient ML's Performance on High, Low and Unassociated Pairs

![Graph showing performance of ML on associated pairs with number of correct answers on the y-axis and trial number on the x-axis.]

Patient AK

AK is a 77-year-old woman who completed one year of college. She suffered a left lacunar infarct in 1995. She exhibits good comprehension and fluent speech characterized by occasional word finding difficulties and phonological paraphasias. Like ML, AK appears to exhibit a STM impairment for lexical-semantic information.
Phonological processing and STM

AK demonstrates generally good phonological processing and STM capacity (see Table 1). Table 3 illustrates that AK's performance is within the range of controls on all phonological processing tasks except for the average of 1- and 2-syllable nonword repetition where she falls just below the range of controls (70 compared to 75 minimum for controls). She was in the range for each length individually. With regard to phonological retention, she showed only a small decline from the immediate (98.5% correct) to the filled delay condition (97%) on the phoneme discrimination task. She showed no difference in repetition of long versus short nonwords, though her pattern of performance on this task was atypical (50% on 2-syllable vs. 90% on 3-syllable nonwords). The only suggestion of a deficit was in the discrimination of short versus long nonwords, but again, there was little variability in performance on this task. Her very large span on the rhyme probe task provides the strongest evidence of preserved phonological STM capacity. Though her span was 4.6 items according to the 75% cutoff criterion, due to experimenter error she was tested on longer lists and scored 92% correct on 6-item lists and 75% on 7-item lists. Further evidence of intact phonological STM is a large phonological similarity effect in memory span (4.2 for dissimilar vs. 3 for similar).

Semantic processing and STM

AK shows greater impairment on semantic tasks. Some evidence suggests that she has a mild semantic processing impairment (see Tables 2 and 5), as she performed below the range of controls on two of the three critical semantic tasks. Her score on the PPVT (79) was
the lowest among the patients and fell 1.4 standard deviations below the control mean. Her score (92%) was at the bottom of the control range for the 2-choice relatedness judgment task. Further, though she was only slightly outside the normal range on the single word-single picture matching task, she made a substantial number of semantic errors, which would suggest a semantic processing impairment. She did perform very well on a synonymy judgment task administered as part of the Philadelphia Comprehension Battery (Saffran, Schwartz, Linebarger, & Bochetto, 1989) (100% nouns, 93% verbs, 96% concrete, 92% abstract), but further evidence of a semantic processing impairment is her poor performance on naming tasks (87% on the PNT and 66% on the BNT). Anomia at the level of phonological retrieval could be offered as an explanation for her poor performance on the naming tasks, but this seems rather unlikely given her mixed performance on other semantic processing tasks which do not require output of phonology (e.g., PPVT, word-picture matching).

AK also shows a mixed picture with respect to semantic retention. Her performance dropped substantially between the 2-choice (92%) and the 3-choice (78%) relatedness judgment tasks, which would suggest reduced semantic STM capacity. However, on the category probe task, AK scored the highest among the patients (span = 3.7), though still outside the range of controls. She also obtained 100% correct on the attribute judgment task. She showed little advantage for words over nonwords in memory span (3.4 for words vs. 3 for nonwords). Thus, in contrast to a clear-cut pattern of good phonological retention abilities, AK demonstrates mixed evidence of semantic abilities. There is some evidence of impairment of both
semantic processing and retention abilities. Her possible semantic processing impairment will be addressed in the definition learning task.

**Composite scores**

Both of AK's phonological and semantic STM composite scores are positive (see Tables 4 and 6), indicating greater STM capacity relative to the other patients on average. Her higher phonological STM composite score than semantic suggests more preserved phonological STM capacity than semantic (see Appendix C).

**Long-Term Learning**

Though AK does not appear to have a severe semantic processing deficit, her impaired performance on some semantic tasks suggests a mild semantic processing impairment. This possibility will be taken into account when analyzing and interpreting her long term learning performance. AK demonstrates a pattern of good phonological STM, together with mildly impaired semantic STM. It was predicted, therefore, that she would show a pattern of performance similar to ML, with better ability to learn novel phonological than semantic information, and she should show a higher level of performance overall. Her performance did confirm the first prediction, showing even greater separation between foreign word and definition pairs learning than ML (see Figure 11). This difference was highly significant as measured by average number of correct responses per trial, \( z(7) = 7.48, p < .0005 \).
To ensure that her performance was not simply a result of a subtle semantic processing deficit (rather than a STM impairment), a more conservative scoring of her data was used for further analysis. In this stricter scoring procedure, all definition items which contained any word which was a part of a missed triad on the three-choice relatedness judgment task was removed from the learning data. Thus, it could not be said that she performed poorly on definition pairs learning due to not knowing the meanings of the individual words.
used. This is also a conservative measure because on the two-choice version of the relatedness judgment task, AK performed quite well, within the range of controls, demonstrating a knowledge of the meanings of the words used. Using this revised scoring procedure, AK still demonstrated a large difference between her learning of novel phonological and semantic forms (see Figure 12). Because some items were eliminated from the definition stimuli but not the foreign stimuli, her performance is represented as a percentage rather than number correct. The gap between the definitions and foreign pairs learning decreased slightly, which would account for any subtle semantic processing deficit (or else noise). However, there still remains a significant difference between the two types of learning, \( t(7) = 5.39, p = .001 \).

On the adjective-noun pairs varying in degree of association, AK's performance was similar to ML's in several respects. She showed no significant difference between high and low associated pairs (see Figure 13), \( t=1.85, p=.11 \), and on the unassociated pairs her performance dropped substantially to a level very similar to her performance on the definition pairs. Like ML, many of her errors on the unassociated pairs task were items recalled from the list, but paired with the wrong initial item.
Figure 12
Patient AK's Definition and Foreign Pairs
Learning Using Revised Scoring Procedure
Figure 13
Patient AK's Performance on
High, Low and Unassociated Pairs

Discussion
AK shows a similar learning pattern to ML, with better ability to
learn material containing novel phonological forms than novel
semantic information. A possible explanation for AK's performance
would be that she has intact phonological processing, but impaired
semantic processing, which would interfere with learning novel
semantic information because she could not even encode the words
used to convey the material. However, her performance on several
discriminatory semantic tasks suggests only a mild processing impairment. Furthermore, the use of the more stringent scoring criteria took into account any semantic deficit on her learning performance. It appears that her poor performance on some semantic tasks, as well as the learning tasks, reflects a semantic STM impairment. Thus, AK's data also suggest that the learning of novel semantic information is contingent upon semantic STM abilities.

Given her larger span on rhyme and category probe tasks (see Tables 1 and 2), and on the other memory span tasks (see Table 2 and Appendix A) we would have expected her to perform better on the learning tasks than ML. AK's overall level of performance was not substantially better than his, however. She was slightly, though not significantly, better than him on the foreign word learning, and performed at about the same level on the definitions. Several factors may have contributed to her low level of performance (e.g., some degree of semantic deficit per se or mild anoma); however, there is little in the way of evidence to support or distinguish among any of these possibilities.

It was pointed out previously that both ML and AK produced substantially more target words paired with the wrong stimulus than EA, who produced very few in either the foreign pairs or the unassociated pairs (she produced slightly more on the definition pairs and the high and low associated pairs). AK produced many more of the target words from the group that were paired with the wrong stimulus (average of 18.8 per block across the definition pairs) compared to ML (average 6.5 per block). Thus, her larger span does appear to aid her
in retaining the target words, but for reasons that are unclear, she was unable to form new linkages between the stimulus and target words.

Patient GR

GR is a 54-year-old man who had received his Bachelor's Degree in English and History and was working at the Texas Employment Commission before suffering a stroke in 1989. Detailed information about the location of his lesion has not yet been obtained. GR exhibits good comprehension but reduced output. His speech is characterized by short utterances which are grammatically correct, and word finding difficulty. He demonstrates a semantic retention deficit in STM.

**Phonological processing and STM**

GR's performance on phonological processing tasks indicates the possibility of a slight phonological processing impairment (see Table 1). Table 3 summarizes GR's phonological processing abilities relative to controls. He performed within the control range on all of the critical tasks except the no delay phoneme discrimination task. He scored 94% correct in the no delay condition of the phoneme discrimination task, which is below the range of controls. Interestingly, his performance actually improved slightly with a delay (97% unfilled, 95% filled). Though his was one of the lowest scores among the patients in the no delay condition, his scores were among the highest in the delayed conditions, suggesting that he is very good at retaining representations even if they may have been processed inaccurately. On the nonword repetition task, he performed near the mean of controls on the 1- and 2-syllable stimuli. His performance dropped below the range of controls on the longer stimuli of 3 and 4 syllables. On the discrimination task GR performed almost perfectly, indicating very
good phonological processing capabilities in contrast to his lower performance on the phoneme discrimination task. His very good performance on the delayed conditions as well as the nonword discrimination task suggests that his poor performance on the phoneme discrimination task was an aberration. In any case, any processing deficit which he may have would be very mild.

In the tasks tapping phonological STM ability, he performed better than the other patients on average (see Table 6). He showed no detriment from a delay in the phoneme discrimination task and little decrease in performance as a function of length of nonwords in the discrimination task. Furthermore, his rhyme probe score was relatively high compared to the other patients. He did show a larger decrease in performance on nonword repetition for the longer stimuli, though not as large of a decrement as patient EA. GR demonstrated a very large phonological similarity effect (4.2 dissimilar vs. 2.4 similar), suggesting retention of the phonological information in the word lists. Thus, GR's general pattern reflects very good phonological processing abilities and preserved phonological STM capacity.

**Semantic processing and STM**

GR performed at a normal level on each of the critical semantic tasks (see Tables 2 and 5). He scored well above the mean of controls on the PPVT (117), and within the range of controls on the two-choice relatedness judgments (94%) and on the single word - single picture matching task (97%). He does have some difficulty with other semantic tasks which require production, such as the PNT (84%) and the BNT (82%). It appears that much of his difficulty can be attributed to a slight anoma stemming from an inability to retrieve phonology from
meaning, since he performs so highly on tasks which do not require output.

On semantic STM tasks, GR shows some impairment. For example, his score on the category probe task was quite low (2.2); his score fell substantially from 94% on the two-choice relatedness judgment task to 83% on the three-choice version, which was only slightly better than AK. He scored 90% on the attribute judgment task, but improved to 95% on the reduced memory load version, and 98% with visual administration. He does, however, show some semantic effects on memory span measures (3.3 for words vs. 2.6 for nonwords).

**Composite scores**

Both composite scores were positive for GR (see Tables 4 and 6), suggesting that, on average, he is less impaired on these STM measures than other patients. However, he obtained a much larger phonological STM composite score than semantic (see Appendix C), suggesting a greater capacity to retain phonological than semantic information.

**Long-Term Learning**

GR's relatively intact phonological processing and STM capacity, together with his impaired semantic STM capacity, led to the prediction that he would be better able to learn novel phonological information compared to novel semantic information. When testing began, it was learned that GR had studied Spanish extensively in high school and college. Though he could not speak or produce Spanish spontaneously, he was familiar with much vocabulary. Therefore, new foreign stimuli were constructed, using the same English words as the
target items in the original pairs. The new foreign items were constructed so as to parallel the form of the original Spanish stimuli (i.e., C-V-C syllable construction was matched) but with distinct phonology. For example, instead of the real Spanish word "chiste" for "joke," the new stimulus was "flindo." Five age-matched controls were tested with the new stimuli to determine if they were comparable in difficulty to the original stimuli. If anything, the new stimuli were more difficult than the original as measured by average number of correct responses per trial, $t(7) = 7.38, p < .0005$ (see Figure 14).

In accord with the predictions, GR did perform significantly better on the foreign than the definition stimuli (see Figure 15) as measured by average number of correct responses per trial, $t = 6.84, p < .0005$. As these stimuli appeared to be even more difficult than the original stimuli for controls, and controls show an advantage for the definitions over the original foreign stimuli, this finding seems particularly robust.
Figure 14

Comparison of Controls' Performance

on Original Versus Revised Foreign Stimuli
Figure 15
Patient GR's Performance on Definition and Revised Foreign Pairs

On the adjective-noun pairs varying in degree of association (see Figure 16), GR demonstrated a larger difference between his performance on the high and low associated pairs than ML and AK, who did not demonstrate any significant difference. GR was slightly below the normal range for highly associated pairs, and substantially below the normal range for low associated pairs. Like ML and AK, he
did exhibit some learning of the unassociated pairs, though to a much lower degree than the associated pairs.

Figure 16
Patient GR's Performance on High, Low and Unassociated Pairs

Discussion
In line with predictions following his profile of processing and STM abilities, GR was able to learn the novel phonological stimuli to a greater degree than the novel semantic information. Again, this is in the opposite direction of controls' performance, who show an advantage in learning novel semantic information. On the adjective-
noun pairs, GR demonstrated high performance on the high and low associated pairs, though, unlike ML and AK, he did show a difference between the two. His performance on the unassociated pairs was similar to that of both ML and AK in that he did show some learning, in contrast to EA, who did not. Also like ML and AK was his frequent recall of target words from the block, which were paired with the incorrect stimulus.

Patient AB

AB is a 76-year-old male who was a practicing lawyer. In 1979 he was operated on for a left frontal hematoma after experiencing right-sided weakness and language difficulties. His single word processing is good (above the mean for controls on the BNT and PPVT). General speech comprehension appears good, though he demonstrates mild impairment for auditory comprehension of some sentence constructions. His spontaneous speech is characterized by reduced phrase length and word finding difficulties. While it is grammatically correct, it contains little content information. Prior evidence indicates that, contrasted with EA, AB showed better phonological retention capacity and worse semantic retention capacity (R. Martin, Shelton & Yaffee, 1994).

Phonological processing and STM

AB's phonological processing appears to be slightly impaired (see Tables 1). As illustrated in Table 3, AB's performance is below the range of controls on two of the four critical phonological processing measures. He scored 94% correct in the no delay condition of the phoneme discrimination task, below the range of controls. He was in
the range of controls on the average of 1- and 2-syllable nonwords for both the repetition and discrimination task, and slightly below the range on the one-item lists of the rhyme probe, missing only one item, like several of the other patients.

With respect to phonological retention, AB, like ML, shows mixed evidence of preserved capacity. Overall his performance is better than ML, however. His performance dropped somewhat in the phoneme discrimination task in the unfilled delay condition (91%), and decreased even more with a filled delay (85%), suggesting that his ability to retain phonology over time is impaired, especially when rehearsal is prevented. His performance also decreased substantially as a function of number of syllables on the nonword repetition task. He did not show a large decrement in performance between the short (1- and 2-syllable) and long (3- and 4-syllable) nonwords in the nonword discrimination task. (As discussed previously, however, there was little variability in performance on this task). Finally, he demonstrated a large rhyme probe span (4.6), the largest among the patient scores. Further evidence of some preserved phonological retention is a phonological similarity effect in memory span (2.8 dissimilar vs. 2.2 phonologically similar). Thus, though AB demonstrates mild phonological STM impairment on some tasks, it appears more preserved relative to his semantic STM capacity.

**Semantic processing and STM**

AB also demonstrates mixed evidence regarding his semantic processing abilities (see Table 2). As shown in Table 5, AB performed below the level of controls on two of the three critical semantic tasks. He only performed within the control range (above the mean) on the
PPVT. On the two-choice relatedness judgment task, AB performed much worse, obtaining the lowest score among all the patients (63%), well below the range of controls. On the single word-single picture matching task, he scored only 3% below the range of controls, but made many more errors with semantically related distractors than the controls. It would seem premature to conclude that AB has a severe semantic processing deficit, however, considering his very strong performance on some single-word processing tasks. His score on the PNT (89%) was within one standard deviation of the mean, and was higher than scores of several of the other patients who scored better than AB on more complex tasks. He also performed above the mean of controls on the BNT, scoring 90.5% compared to 84% for controls. His very high performance on both the PPVT and the BNT suggests excellent comprehension. On intuitive grounds, we assume that he knows the information being tapped in the tasks on which he scores so poorly (i.e., on the relatedness judgment task, he knows which of "convict," "thief," and "inmate" are not necessarily in jail, but this needs to be empirically tested). Some evidence which suggests support of this assumption is that he performed as well as EA on property judgments about statements in the form "belt has buckle" (Martin, Shelton & Yaffee, 1994). It appears that AB starts having difficulty when he must compare two or more words.

His performance was low on all tasks which implicate STM (see Table 6). His span on the category probe task was only 2.2. He showed some decrease in performance (8%) on the three-choice relatedness judgments compared to the two-choice version, but his score on the two-choice version was already very low. AB performed very poorly
on the attribute judgment task, scoring only 50%. He improved to 83% on the revised version, and 100% on the visual version. Finally, the lack of effect of semantic variables on memory span is further evidence of a severely reduced semantic STM capacity. He showed very little advantage for semantically meaningful material over nonsense stimuli (span = 2.5 for words vs. 2.4 for nonwords).

**Composite scores**

AB obtained a positive phonological composite score (see Table 4) compared to a negative semantic STM composite score (see Table 6), reflecting the greater preservation of his phonological STM capacity (see Appendix C).

**Long-Term Learning**

Though impaired on both types of STM capacities, AB demonstrated a greater deficit in semantic STM capacity. Thus, it was predicted that he would show a greater ability to learn the novel phonological information compared to the novel semantic information. However, AB demonstrated very little learning of any of the list types. There was no significant difference between his learning of the definition and foreign pair stimuli because his performance was at floor on both (see Figure 17).

In the learning of the adjective-noun pairs, AB was also unable to learn even the highly associated pairs. Testing was not continued beyond the first block of the low associated pairs because AB was already performing near floor level (see Figure 18).
Figure 17
Patient AB's Performance on Definition and Foreign Pairs

Patient AB

Number Correct

definitions
foreign

Trial Number

0 1 2 3 4 5 6 7 8
AB was tested on the recognition paired associate task in the hopes that his performance would be elevated enough to observe a difference in his phonological and semantic learning abilities. On the six blocks which he has completed (three foreign and three definition blocks), his performance has been elevated substantially relative to the recall version of the task (average of 42 correct responses per recognition block compared to 6 correct responses in the recall blocks). He actually performed at a higher level on the definition pairs (see
Figure 19), but showed little improvement over performance on the first trial. In contrast, he demonstrated definite learning and improvement on the foreign stimuli. Since controls performed at ceiling on the recognition blocks, relative difficulty of the different list types was not assessed. AB performed at a higher level on the definitions throughout all trials, but showed little additional learning over time. In contrast, he showed definite learning of the foreign stimuli. It is possible that in this recognition paradigm, the definition pairs are simply easier than the foreign pairs.

Discussion

AB's striking inability to learn any of the types of paired associates in the recall tests, even highly associated pairs, was very surprising, especially in light of past performance on paired associate tasks on the Wechsler Memory Scale-Revised (Wechsler, 1987) in which he was able to recall highly associated pairs. It was predicted that though he would be impaired on all learning tasks relative to controls due to his STM impairments, he would be less impaired at learning novel phonological information compared to semantic information. However, because his performance was so low on all of the tasks, there was no difference observed in his ability to learn the two types of material.
Further testing will also be conducted to investigate AB's semantic processing impairment. Considering his severe semantic STM deficit which impairs all semantic processing beyond the single word level, it is not surprising that he is severely impaired on learning tasks which require the formation of eight new connections simultaneously. Such a severe impairment would provide an explanation for his overall poor performance on the learning tasks. He would have
difficulty retaining and connecting eight different concepts to any type of stimulus, whether definitions, known words, or English translations of foreign words. One interesting aspect of his performance on the recognition blocks is AB often chose an extra-list distractor which had never been presented in the study phase as his response (24% of incorrect responses). This suggests that AB sometimes does not even recognize words which have been presented in previous trials, which could reflect a failure to process or encode all of the stimuli as they are presented.

Patient IG

IG is a 78-year-old man who suffered a cerebral vascular accident affecting the left posterior parietal lobe following a coronary bypass in 1988. He is a college graduate and had been employed as an industrial engineer. IG exhibits good comprehension but slightly impaired speech production in the form of slowed speech and phonological paraphasias. He experiences word finding difficulties in spontaneous speech and in single word processing tasks.

Phonological processing and STM

IG demonstrates fairly good phonological processing ability (see Table 1). Table 3 illustrates IG's phonological processing abilities relative to controls' performance. He is within the range of controls on two of the four measures. He performed at a normal level on the phoneme discrimination task with no delay (99%) and on the nonword discrimination task for all syllable lengths. On the rhyme probe task, he made one error on the 1-item list length. He performed poorly on the nonword repetition task. Given the discrepancy between his
performance on the repetition task and the nonword discrimination task, the output of phonology may be impaired for this subject.

With regard to phonological retention (see Table 4), he showed a 7% decline for the filled delay condition relative to no delay in the phoneme discrimination task. His rhyme probe span was only 3.0. Also, on the nonword discrimination task, he showed one of the larger drops between 1- and 2-syllable and 3- and 4-syllable nonwords. He showed less decrease in performance on the nonword repetition task between the short and long words, but this finding is complicated by his poor performance in repeating single-syllable nonwords. He does demonstrate a phonological similarity effect (3.3 for dissimilar vs. 2.0 for similar) on memory span, indicating some short-term retention of phonology. Overall, IG is one of the more impaired patients on phonological retention, though he is still less impaired than EA.

**Semantic processing and STM**

IG appears somewhat more impaired on semantic tasks (see Table 2). As illustrated in Table 5, IG scored below the range of controls on two of the three critical semantic processing tasks. His standard score on the PPVT (98) indicates that he has good comprehension. However, he performed just below the range of controls on the two-choice relatedness judgment task (91%) and on the single word-single picture matching task (94%). Most of his errors were accepting a semantically related picture, and he made more of these types of errors than controls, indicating some semantic processing deficit. Further evidence of a semantic processing deficit is his poor performance on naming tasks (69% on the PNT and 62% on the BNT). In light of his normal performance on the PPVT which does
not require output, anomia caused by an inability to retrieve the phonology of the target word may account for his low scores on these two naming tasks.

IG’s semantic retention is also impaired on several of the critical semantic STM tasks (see Table 6). His category span was only 1.8, the lowest among the patients, along with patient ML. He showed a large drop in performance (13%) from the two-choice to the three-choice relatedness judgment task, and showed no advantage for words over nonwords on the span task (in fact, he showed a slight advantage in the opposite direction). Surprisingly, he scored 100% on the attribute judgment task, which has been diagnostic of semantic STM deficits for other patients (e.g., ML and AB).

Thus, it appears that IG has some semantic processing impairment. He also demonstrates anomia in naming tasks and impaired semantic STM on a variety of tasks. The anomia appears to be caused by an inability to retrieve phonology from semantics. On tasks which access the semantics without requiring production, IG performs better (i.e., PPVT, single word-picture matching), though still below the level of controls on some tasks. Another feature of his performance is a large effect of frequency in list repetition (list repetition task varied for frequency and imageability in the PCB). IG had a very reduced recency effect, as most of his errors occurred for the final items in the lists. A reduced recency effect in list repetition is generally taken to indicate a phonological STM deficit. IG’s case is the least clean of the patients in this study in terms of semantic versus phonological STM impairment, and his case is complicated by anomia.
IG's pattern of performance across these tasks is similar in several respects to that reported for patient MS (Martin & Lesch, 1996). MS contracted herpes encephalitis which caused damage to the left temporal lobes and resulted in impaired language abilities while other cognitive abilities were preserved. MS demonstrated a very large digit span and rhyme probe span, indicating good phonological STM capacity. In contrast, he did not show an advantage for words over nonwords on a memory span task, suggesting that he does not benefit from semantic information inherent in words. The pattern described thus far would suggest preserved phonological processing and STM with impaired semantic processing. On the PNT, MS scored only 43%; however, most of his errors were circumlocutory descriptions of the target, which suggests that he retained semantic information about the word, but was unable to access phonology from the semantic representation. His performance was largely related to frequency, as he named 87% of high frequency items and only 20% of low frequency items. On semantic tasks which tap relatively detailed knowledge about words and their meanings (e.g., PPVT and detailed attribute questions concerning a large set of pictures from different categories), MS performed relatively well, demonstrating at most a mild deficit in comprehension. Further, his performance on list repetition revealed a reduced recency effect which is taken to indicate a phonological STM impairment.

Martin and Lesch explain MS's pattern of performance by postulating separate input and output phonological codes in language processing and STM. MS's impairment is an inability to access output phonological codes from preserved semantic representations,
illustrated by his poor naming ability despite semantic descriptions of the items. This link between semantics and output phonology accounts for normal benefits derived in memory for words over nonwords. Impaired ability to access phonology from semantics would account for MS's lack of advantage for recall of words over nonwords on the memory span task.

IG's performance can be explained with a similar account, though it is complicated by other impairments not demonstrated by MS. IG's selectively worse performance on naming tasks (BNT, PNT) relative to other semantic tasks which do not require output phonological responses can be explained by an inability to retrieve output phonological codes from semantic representations. In line with this hypothesis is IG's lack of advantage for words over nonwords. Like MS, he actually shows a slight advantage in the opposite direction, and he shows a large effect of frequency on list repetition. There are differences between IG and MS's performance, however, which suggest that IG has additional impairments. IG does not produce circumlocutory descriptions of items in memory tasks. This behavior of MS suggested that he was retaining the semantic representations of the items, but simply could not access the phonology. IG's performance on a variety of tasks suggests that he has impaired retention of the semantic representations besides an inability to access the phonology (e.g., much better performance on the relatedness judgment task when the memory load is reduced). Furthermore, IG's phonological retention abilities are not as well-preserved as those of MS, as he does not demonstrate as large of a rhyme probe span and his performance declines in the phoneme discrimination task with the introduction of a
delay. He does demonstrate a phonological similarity effect, suggesting that he is able to retain phonology to some degree. Thus, a combination of an inability to access phonology from semantics, impaired semantic STM capacity, and reduced phonological STM capacity may account for his pattern of performance.

**Composite scores**

IG's composite phonological and semantic STM scores are negative (see Tables 4 and 6), suggesting he is somewhat more impaired on both measures than the average of other patients (see Appendix C). He is slightly more impaired on the semantic than the phonological measure, suggesting greater impairment of semantic STM difficulties.

**Long-Term Learning**

Considering IG's inability to retain or access output phonology from semantics, he should have difficulty on all types of paired associate learning tasks which require recall and production of the target words. He was impaired at both phonological and semantic STM measures, so poor performance generally would be predicted, with little difference between the foreign and definition stimuli. Indeed, IG was unable to demonstrate appreciable learning in either the foreign or definitions paired associate tasks (see Figure 20), in line with his impaired processing and retention of both types of information, and he showed no difference between learning novel phonology and novel semantics. Testing was discontinued after one block each of the foreign and definitions pairs because he became somewhat frustrated with the task and his inability to complete it.
IG's learning of the adjective-noun pairs varying in level of association was not only below the level of controls, but also substantially below the level of all other patients tested (except AB), who were at least able to learn the highly associated pairs. While he performed better on the high and low association pairs than the foreign and definition pairs, and showed definite learning, the task was very difficult and frustrating for him, and testing was discontinued after one low associated block (see Figure 21). Given the
large decrease in level of performance between low associated and unassociated adjective-noun pairs for both controls and patients, it was assumed that IG would be unable to learn the unassociated pairs.

Figure 21
Patient IG's Performance on High and Low Associated Pairs

Three blocks each of the foreign and definition pairs recognition task have been administered to IG and his performance has greatly increased (see Figure 22). He has averaged 47.3 correct responses per recognition block, compared to 9 in the recall blocks. He has
demonstrated a slight advantage for definitions over foreign pairs so far, but more data is needed before an assessment can be made. Although IG and AB seem to perform at similar levels on the recognition blocks, IG chose fewer extra-list distractors (17%), compared to AB (24%). This difference suggests that IG has somewhat greater ability to encode and retrieve semantically meaningful material than AB.

Figure 22
Patient IG's Performance on Recognition Definition and Foreign Pairs
Discussion

IG performed very poorly on all types of the recall paired associate tasks. Other patients were able to reach criterion for at least the highly associated pairs, while IG and AB never did. It is believed that IG's inability to learn the pairs is related to impaired access to output phonology from semantics, combined with semantic and phonological STM deficits. Because he has difficulty in accessing output phonology for his responses, it was predicted that IG would show substantial improvement in the recognition version of the paired associates which does not require output response. Further, because he is slightly more impaired for the retention of semantic information than phonological information, it was predicted that he would show some advantage for learning novel phonological information compared to novel semantic information on the recognition blocks. These data are in the process of being collected.

Summary of Patient's Performance

Table 7 provides a summary of all of the patients' performance on each of the learning tasks. As predicted by their patterns of STM impairment, the patient with a phonological STM deficit (EA) was better able to learn the pairs containing novel semantic information than pairs with novel phonology, while the patients having semantic STM impairments (ML, AK and GR) were better able to learn pairs containing novel phonological information. (AB and IG, who were unable to learn either type of information, are discussed below). This dissociation in performance on the two types of learning correlates highly with the STM composite scores (see Table 8). Including only the four patients who demonstrated learning on the foreign and definition
Table 7
Average Number of Correct Responses
Per Block (64 Possible)

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<th>Controls</th>
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<th>EA</th>
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pairs, the correlation of the difference between foreign and definition learning and the difference between phonological and semantic STM composite scores is almost perfect, $r=.98$, $p=.02$. Even when AB and IG, who showed no difference between foreign and definition learning, are included, the correlation remains high, $r=.72$, though $p>.05$. Obviously these are very small sample sizes (N=4; N=6), so the generalizability of the findings to other cases may be questioned. These findings do suggest, however, that preserved phonological and semantic STM abilities are good predictors of ability to learn novel phonological or semantic information.

Two patients (AB and IG) were unable to demonstrate appreciable learning on the recall version of the paired associates. It is hypothesized that their inability stems from two different types of impairment: a severe semantic STM deficit for AB which affects performance on all tasks beyond single-word processing, and a combination of inability to access output phonology from semantics and semantic and phonological STM deficits for IG. It was hypothesized that these patients' performance would improve with the easier recognition version of the paired associate task and that AB would show a difference between learning of the two types of pairs. Results so far have not confirmed this hypothesis. In fact, both AB and IG have shown somewhat of an advantage for learning the definitions over the foreign word pairs. Controls also performed slightly better on the definition stimuli, but since they performed near ceiling for both types, the relative difficulties of the two tasks cannot be determined. Future testing which increases the difficulty of the task (i.e., by increasing the number of items to be learned) may demonstrate a
difference in the relative difficulty of learning these two types of stimuli.

The pattern of performance on the adjective-noun pairs having different levels of association was opposite to that which was originally predicted. It was thought that preserved semantic STM capabilities would enable EA to easily learn items with pre-existing associations and to form new associations between meaningful items. Conversely, patients with impaired semantic STM (ML, AK and GR) were predicted to show a large effect of degree of association between the items, and be unable to learn unassociated items since the semantic representations could not be held in memory in order for new connections to be formed. However, of the four patients who completed testing of the associated pairs, patient EA had the lowest performance at each level of association (see Table 7). The other patients (ML, AK, and GR) performed much more highly, especially on the unassociated pairs which it was predicted they would be unable to learn.

Contrary to predictions, ML and AK did not show a significant difference between the high and low associated pairs, which suggests that any degree of pre-existing semantic association coupled with good phonological abilities is enough to support recall of the item. The degree of association between items did seem to affect GR's performance, however, in that he showed a difference between the high and low associated pairs. It is unclear why his performance differed in that respect.

The unassociated pairs are quite similar in form to the definition pairs in the sense that they both consist of an arbitrary pairing of two
semantically meaningful stimuli. Like controls, EA performed considerably better on the definitions than on the low associated pairs. One possible explanation for this discrepancy in performance on the two types of pairs is that the definitions provide more semantic support than the one-word stimuli in the associated pairs. Whereas the associated stimuli are adjective-noun pairs, the definitions often provide highly imageable cues to the target (e.g., "to shorten a horse's mane" = "hog"). As richer semantic support enabled EA to perform better on the definitions, it would be predicted that EA would perform better on any type of learning test as a function of the imageability of the stimuli.

ML, AK and GR demonstrated significant learning of the unassociated pairs, despite no meaningful relationship between the items. Presumably their relatively strong phonological STM capacity aided their retrieval of the unassociated stimuli. ML, AK and GR demonstrated similar levels of performance on the unassociated pairs as on the definition pairs. Apparently, the richer semantic content in the definitions gave them little advantage for learning over the unassociated pairs. Both cases required a reliance on the phonological record of the pairing.

ML, AK, and GR's reduced performance on the unassociated pairs compared to those with a meaning relation complements the finding reported in Martin and Romani (1994) in which AB (patient with a semantic STM deficit) demonstrated poorer performance on a sentence anomaly judgment task as a function of the number of words which had to be held in an unintegrated fashion before a response could be made. ML has also been tested on these materials and shows the same
pattern with an even larger effect than AB. Some of the stimulus sentences contained adjectives either preceding or following the nouns which they modified. AB and ML were worse at correctly detecting anomalies when the incongruous adjective preceded the noun and was separated from the noun by intervening words. Similarly, on the paired associate learning task, high and low associated pairs can be immediately "integrated" into a meaningful (pre-existing) unit, whereas the unassociated pairs cannot. Lacking any integration of the two stimuli which would allow for the formation of an association between them, the subject is forced to rely only upon a phonological record. Thus ML, AK and GR were able to learn a small number of the unassociated pairs, whereas EA was almost completely unable to complete the task, as she does not retain the phonological record.

The imageability of the unassociated pairs may also explain why EA was unable to learn them, when it is claimed that she has a similar deficit to that of PV (Baddeley, Papagno, & Vallar, 1988), and perhaps KF (Warrington & Shallice, 1969), who were able to learn associations between meaningful but unrelated items, presumably by relying on semantic processing. The stimuli used in PV's paired associate learning task, however, were composed of concrete, high frequency (greater than 25 occurrences per 500,000) words only. KF was tested using the 10 pairs on the Wechsler Memory Scale-Revised (Wechsler, 1987), six of which were highly associated (e.g., fruit - apple) and four of which were unassociated (e.g., crush - dark). Though KF's testing did include some unassociated pairs, there were only four included in the block. In contrast, eight unassociated pairs were presented to EA in each block. This difference could account for KF's better performance than EA for
the unassociated pairs, since EA did not have the benefit of pre-existing associations between any of the pairs. Thus, PV and KF were not tested using stimuli systematically controlled for imageability and level of association. It is hypothesized that they would have performed poorly if unassociated words having low imageability had been used. The unassociated pairs used in testing EA were composed of adjective-noun pairs, which were certainly less imageable than PV's concrete pairs. EA's performance suggests that a reliable phonological record may be necessary for learning abstract words and arbitrary relationships, as well as for learning novel phonology. However, this supposition needs empirical testing. She may perform better on highly imageable unassociated pairs compared to abstract unassociated pairs. Patients who rely on phonology may show less effect of imageability.

Almost all of EA's errors on the unassociated pairs, and on the foreign word pairs, were failures to respond. This suggests that without any kind of semantic clue to the identity of the target words, and with her severely impaired phonological STM, she could not recall the phonological forms at all during test. In discussion of their strategies for completing the unassociated pairs learning task, most controls report the formation of elaborate strategies to pair the two items together. They usually report either visualizing the items interacting in some way, or forming some other unique connection between them. Though she should be able to implement such a strategy with her intact semantic capacity, EA did not appear to do so spontaneously. If this type of strategy were suggested to her and she was given some examples, her performance on the unassociated pairs could possibly be raised to the level of her definition learning. Because
she loses the phonology, however, she would likely make errors consisting of other components of the mental connections formed between the two items, similar to the semantic substitution errors which occurred in some of her responses. Clearly this strategy would be of little benefit to her in learning the foreign pairs, though controls do report the formation of elaborate associations between the foreign words and their translations. EA would almost certainly be unable to retain the phonological forms of the foreign words to form such associations.

Unlike EA, who very rarely produced any of the target items in the unassociated pairs, ML, AK and GR often produced target words from the block, but paired with the wrong stimuli. This indicates that they were able to remember the specific items (phonological forms), but often did not retain the arbitrary associations between them, which were devoid of any pre-existing semantic relationship.

GENERAL DISCUSSION

Traditional and current models of memory (e.g., Baddeley & Hitch, 1974; Baddeley, Gathercole and Papagno, 1998) have described some very important aspects of the memory process, and have made extensive efforts to understand and describe the mechanism behind memory. Baddeley and colleagues' explanation of the role of the phonological loop in the short-term retention of information is compelling as it can account for many of the phonological effects in human memory (e.g., articulatory suppression, phonological similarity, and word length effects). However, this one-sided model which is so widely accepted fails to take into account any of the current research which indicates that there are other components of STM beyond the
phonological component described in that model (N. Martin & Saffran, 1997; R. Martin & Romani, 1994; R. Martin, Shelton, & Yaffee, 1994).

In his most recent article (Baddeley, Gathercole & Papagno, 1998) Baddeley and colleagues designate the phonological loop as primarily a language learning device. In light of the data presented in this paper, that is a reasonable assertion, to the extent that the phonological loop is simply their conception of the mechanism behind phonological STM. Clearly, as illustrated by patient EA's inability to learn foreign words having novel phonology, it appears that phonological STM is essential for the acquisition (long-term learning) of novel phonological forms. There have been several patients of this type reported in the literature (e.g., Baddeley, Papagno & Vallar, 1988; Trojano, Stanzione & Grossi, 1992). This type of patient with a relatively pure phonological STM deficit, however, seems to be one of the least common types of STM patients. The overwhelming majority of patients tested in the present study had relatively preserved phonological processing and STM, but impaired semantic STM (e.g., ML, AK, GR, AB, and perhaps IG).

It is unclear how use of only the phonological loop model could account for these patients' performance. First of all, they show impairment in the retention of specifically semantic material relative to phonological material (e.g., category vs. rhyme probe, semantic vs. phonological effects on memory span, etc.) Secondly, they show an advantage for learning novel phonological information relative to novel semantic information. Baddeley and colleagues claim that the function of this mechanism is not to remember familiar words, but to learn new ones. However, they claim that the "contribution of this
system to the short-term retention of familiar verbal material in conventional memory-span-type tasks is...merely an incidental by-product of the primary function of the phonological loop," and that "when possible, people use existing language knowledge to mediate their attempts at verbal learning" (Baddeley, Gathercole & Papagno, 1998). According to this reasoning, patients with impaired phonological loops should also have impaired retention of familiar, meaningful verbal material. Further, as "existing language knowledge" cannot be relied upon for the retention of novel semantic information, they offer no other mechanism for the retention of novel semantically meaningful material beyond the simple by-product of the normal functioning of phonological STM. If that were the case, then there is no explanation of why patients with relatively intact phonological loops would be impaired at learning specifically novel semantic information compared to novel phonological information. In fact, however, sensitive measures of the different components of STM indicate that these patients are specifically impaired primarily in the short-term retention of semantic information. The present study has extended this argument by showing that these specialized and dissociable components of STM are essential for the long-term learning of corresponding material. As Baddeley et. al. correctly assert, phonological STM deficits impair patients' learning of novel phonology; however, the converse of this finding is also true, namely, that semantic STM deficits impair the learning of novel semantic information.

We would also argue that phonological STM is not used only for the long-term learning of novel phonology. Martin (1993)
demonstrated that phonological STM was essential for the verbatim repetition of sentences. Further, phonological STM capacity appears essential for the learning of abstract words or abstract relationships. As discussed earlier, patient PV (Baddeley, Papagno, & Vallar, 1988) was able to learn meaningful associations at a normal level. However, these stimuli were not controlled for frequency and imageability. Highly imageable words may support the reliance upon the unimpaired (or less impaired) semantic component of STM. Words having low imageability, however, may not elicit enough semantic activation to support their short-term (or long-term) retention. This would suggest that a phonological record is important not only for the long-term learning of novel phonology, but also for abstract concepts and relationships. This idea was reaffirmed by patients' performance on the unassociated pairs. With a severely impaired phonological STM capacity, EA was unable to learn the unassociated pairs to any appreciable degree. She could not recall the target words to guess, even in an incorrect pairing. In contrast, patients with semantic STM deficits (ML, AK, and GR), while still impaired relative to controls, were much better able to learn the unassociated pairs than EA. Even when paired incorrectly due to an absence of a semantic relationship between the items, the patients were able to recall many target words.

Some patients (AB and IG) seemed unable to learn either type of material, though their patterns of STM impairment would suggest relatively superior learning of novel phonological information as compared to novel semantic information. Two separate causes of their inability to learn were suggested. It is proposed that IG was unable to demonstrate learning because of an inability to access output
phonology from semantics. While the original paired associate learning task requires output of the target words, the recognition paired associate task would preclude the need to produce phonology. Therefore, his performance should be elevated and he should show an advantage for learning novel phonology on the recognition task because of a reduced semantic STM capacity. AB, on the other hand, has a severe semantic STM deficit which impairs semantic processing beyond the single word level. It appears that this impairment globally affects his learning of all types of paired associates.

An understanding of the different components of STM and a knowledge of a patient's particular pattern of STM deficit can help in identifying relative cognitive strengths and developing strategies and techniques to provide support for the impaired capacity. For example, patients with phonological STM impairments should have more difficulty with everyday tasks such as committing new names or phone numbers to memory than remembering a shopping list. As illustrated by this study, it would probably be an exercise in futility and frustration for a patient with an impaired phonological STM capacity to attempt learning foreign language vocabulary, whereas a semantic STM deficit might still allow for some degree of success. Someone with a phonological STM impairment might be better suited for the learning of new concepts, such as in a literature class. In short, knowledge of the type of STM impairment sustained by the patient can be predictive of the type of long-term learning he or she will best be able to accomplish.

While the function of the phonological component of STM has been widely reported in the literature and used as a basis for the
development of memory models, the semantic component has been largely neglected despite its substantial contribution to the memory process. Working memory models must account for these and other (e.g., syntactic) dissociable components of STM reported in the literature. For example, R. Martin and Lesch (1996) represent the separate components of verbal STM as limited-capacity buffers which hold the representations which are created as output from the dissociable components of language processing. Deficits can occur separately in any of the processing modules or STM buffers, which will differentially affect language processing, STM performance, and long-term learning. Further, evidence from patient MS (R. Martin & Lesch, 1996; R. Martin, Lesch & Bartha, 1997) and IG (reported here) suggests that input and output phonology are separate buffers and impairment can affect them separately. The viability of proposed memory models must be judged on the basis of how well they can account for all types of STM impairments, not just phonological.
References


Appendix A

Patient Span Data:

Phonological and Semantic Effects on Span

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Appendix B

Patients' Performance on Naming Tasks

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* AB was tested on an earlier version of the BNT than the other patients, but scored above the mean of control subjects (AB 76/84 vs. control mean 70.8, s.d.=11.7).
Appendix C
Comparison Between Semantic and Phonological STM Composite Scores

Composite Phonological and Semantic Scores

Score
EA ML AK GR AB IG Patient

Phon Sem
IMAGE EVALUATION
TEST TARGET (QA-3)