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A PHONOLOGICAL SHORT-TERM MEMORY DEFICIT:
A CASE STUDY

by
Gerri Hanten

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

A Phonological Short-term Memory Deficit: A case study.

by

Gerri Hanten

The performance of a highly literate subject, BS, was assessed on tests of short-term memory. He demonstrated a pattern of performance similar to that of patients having a phonological short-term memory deficit. His profile included an exaggerated phonological similarity effect for auditorily, but not visually presented materials, the absence of a recency effect, a reversed modality effect, and difficulty repeating non-words. In contrast to previously described phonological short-term memory patients, BS performed fairly normally in a foreign language learning task, though his acquisition rate was slower than that of control subjects. This finding is counter to current theory which suggests intact phonological short-term memory is necessary to learning of new phonological forms. Further investigation of BS’s deficit suggested that his areas of preserved performance were the result of strategic reliance upon semantic, lexical or orthographic factors. Thus support is demonstrated for theories of short-term memory that propose multiple components contributing to short-term memory.
Acknowledgements

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## Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>ii</td>
</tr>
<tr>
<td>Acknowledgements</td>
<td>iii</td>
</tr>
<tr>
<td>Table of Contents</td>
<td>iv</td>
</tr>
<tr>
<td>List of Tables and Figures</td>
<td>vii</td>
</tr>
<tr>
<td>General Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Uses of Short-Term Memory</td>
<td>6</td>
</tr>
<tr>
<td>I. Sentence comprehension</td>
<td>6</td>
</tr>
<tr>
<td>II Reading</td>
<td>8</td>
</tr>
<tr>
<td>III Language learning</td>
<td>12</td>
</tr>
<tr>
<td>IV Dictation</td>
<td>18</td>
</tr>
<tr>
<td>Present Study</td>
<td>18</td>
</tr>
<tr>
<td>Biographical background</td>
<td>20</td>
</tr>
<tr>
<td>I. Short-term memory tasks</td>
<td>21</td>
</tr>
<tr>
<td>Tests of Span</td>
<td>21</td>
</tr>
<tr>
<td>Experiment 1</td>
<td>22</td>
</tr>
<tr>
<td>Experiment 2</td>
<td>26</td>
</tr>
<tr>
<td>Experiment 3</td>
<td>29</td>
</tr>
<tr>
<td>II. Tests without production</td>
<td>34</td>
</tr>
<tr>
<td>Experiment 4</td>
<td>36</td>
</tr>
<tr>
<td>III. Non-verbal tests of memory</td>
<td>40</td>
</tr>
<tr>
<td>Experiment 5</td>
<td>40</td>
</tr>
<tr>
<td>Experiment 6</td>
<td>42</td>
</tr>
</tbody>
</table>
IV. Supraspan tests of short-term memory 43
Experiment 7 44
Experiment 8 49
V. Interference tasks 51
Experiment 9 52
Summary of Short-term memory tasks 57
Uses of Short-term memory 59
I. Syntactic processing 60
Experiment 10 61
II. Reading 61
Experiment 11 62
III. Learning using familiar phonological forms 64
Experiment 12 64
IV. Foreign language learning 69
Experiment 13 69
V. Note taking 74
Experiment 14 74
General Discussion 78
References 82
Tables and Figures

Table 1. Repetiton span task: Mean words of list length 5 correctly recalled by BS with regard to position as compared to mean and range of controls ..........................24

Figure 1. Repetition span task: Auditory vs. Visual presentation condition at list length 5 .........................................................25

Table 2. BS's word and non-word repetition. Percentage lists correct by syllable length and list length .................................28

Figure 2. Frequency and imageability repetition span task, 5-item lists. shown as number of words per list correctly recalled by two methods of scoring ..................................................31

Figure 3a Frequency and imageability repetition span task: Words correctly repeated by BS by serial position of presentation and word type .................................................................32

Figure 3b Frequency and imageability repetition span task: Words correctly repeated by control subjects by serial position of presentation and word type ........................................33
Figure 4  Repetition span task: Total number of words of list length 5 recalled by serial position. ........................................34

Table 3.  Probe span tasks: Percentage correct of responses at span 6 for rhyme and semantic probe tasks in the auditory and visual presentation conditions. ................39

Figure 5  Free recall of auditorily presented items, BS vs. Controls and free recall of visually presented items, BS vs. Controls .................................................................46

Table 4  Immediate free recall: Mean number of words recalled by presentation modality. .........................................................47

Table 5  Immediate free recall: BS's substitution errors in auditory and visual free recall. ..............................................................49

Figure 6  Serial digit recall: Mean number of items recalled by BS according to serial position. ....................................................50

Figure 7  Interference task: Mean number of words recalled as a function of presentation condition and distractor type. ......55

Table 6  Interference task: Mean number of words recalled per test list by list presentation condition and distractor type. ..........57
Figure 8  Repeated list learning: Average number of words correct per list by list type (BS). ..................................................66

Figure 9  Repeated list learning: Proportion words correct of the single presentation lists by list type and serial position (BS). ....67

Figure 10 Repeated list learning. Recency effect in repeated LF-LI list for BS. .................................................................68

Figure 11 Repeated list learning. Words recalled per trial of repeated LF-LI list, BS vs. Controls. .................................69

Figure 12 Foreign language learning task: Words correct per trial for BS vs. the mean of the controls in the English-Serbian task and the English-English task. .......................73

Table 8  Dictation task: Percentage correct recorded items. ........77
A Developmental Phonological Short-term Memory Deficit: A case study.

Gerri Hanten

Theories of working memory have tended to focus on the phonological aspects of memory. Because of many empirical findings implicating phonological coding in short term memory, it has been assumed that the main functional component of verbal working memory is a phonological store. For example, the well known working memory model of Baddeley and Hitch (1986) postulates peripheral storage system termed the "phonological loop" which is assumed to underlie performance in verbal working memory tasks, especially span tasks. The phonological loop is divided into two components, a passive storage component, into which auditory verbal material is registered, and an active rehearsal component, which maintains the information in the storage component. The slave system for verbal working memory, along with a separate slave system for visual storage, the visuospatial scratchpad, are the main storage components of the model. The 'central executive' component serves to allocate attention to these slave systems and to interpret information from the slave systems in the performance of tasks. Auditory material is considered to have obligatory access to the phonological store, while visual material must be recoded via the articulatory loop before it is registered in phonological store.

Data from a wide variety of sources can be found to support this type of model. The existence of a rehearsal component is supported by findings from the normal population. Memory span has been shown to be
related to articulation rate (e.g. Baddeley, Lewis, & Vallar, 1984). Longer words are spoken more slowly, thus fewer are remembered than shorter words. It has been suggested that memory span reflects the number of items that can be articulated in 2 seconds (Hitch, 1990). Further, when subjects are prevented from covertly articulating by continuously uttering an irrelevant speech sound (articulatory suppression) a decrement in span is observed. The phonological nature of working memory has been supported in that normal subjects have more difficulty remembering phonologically confusable words than phonologically unrelated words (Conrad & Hull, 1964), and they remember more auditorily presented items than visually presented items in span tasks (Conrad & Hull, 1968), which is attributed to the increased probability of recall of the last few items on a list with auditory presentation. The last items of a list have been considered to be specific to phonological memory. It has been shown that these terminal items are affected by phonological factors, such as rhyme, but not semantic factors (Brooks & Watkins, 1990). These findings have been interpreted as reflecting the obligatory access of auditory verbal information to the phonological store. However, there is some evidence that this interpretation is incomplete. The unattended speech effect, (Colle & Welsh, 1976; Salame & Baddeley, 1982) is the finding that immediate recall for visually presented items is impaired when presentation is accompanied by irrelevant speech sounds. The effect has been found with nonsense verbal material and unfamiliar languages and is greater when the phonemes of the unattended material are similar to the items to be recalled (Salame & Baddeley, 1982). The unattended speech effect has been taken
as evidence that traditional short term memory tasks rely on the phonological processing of verbal materials. However, Jones, Madden, & Miles (1992) discovered that the "speech-ness" alone of the irrelevant auditory signal does not account for the disruption in memory for verbal material. They found that the irrelevant speech signal must be accompanied by a pattern of changing acoustical states for disruption to occur, presumably by gaining access to the phonological store. This suggests that acoustical properties of the speech signal may be as important to short term memory tasks as are phonological properties.

In the neuropsychological literature, a number of patients with severely reduced span have been described whose impairments appear to arise from a phonological short term memory deficit. These patients typically show no word length effect, a phonological similarity effect for auditory, but not visual material, an absent or reduced recency effect, and a reverse modality effect (accounted for by the assumption that these patients have a preserved ability to retain visual information which supports recall). Martin and her colleagues (Martin, Shelton & Yaffee, 1994) have worked with a patient, EA who has a very reduced span (1 or 2) and yet is fluent and has normal articulation. She is deficient in repetition, however, and her errors are often semantic in nature suggesting semantic involvement in short term memory processes. Another patient with a very reduced span, PV, shows a similar pattern. PV shows no word length effect and no effect of phonological similarity with visual stimuli, but has a normal articulation rate in speech (Vallar & Baddeley, 1984). These patients demonstrate that articulatory processes can be dissociated from the ability to retain
phonological codes. A third patient, MDC, also shows a pattern which is hard to account for by an articulatory processing deficit (Vallar & Cappa, 1987). She has an auditory span of 7 and shows a normal phonological similarity effect and word length effect for auditory stimuli. However, with visual stimuli her span is reduced and she fails to show phonological similarity effects and word length effects. If there exists one functional unit of phonological memory, then how is it that MDC, who, based on her performance with auditory materials may be thought to have an impaired phonological store, can show the effects usually associated with phonologically based processing with auditory, but not visual stimuli?

Recent research has demonstrated the involvement of semantic processes even in tasks that have been traditionally assumed to make use of only phonological processes. Martin, Shelton and Yaffee (1994) investigated two patients with very reduced memory spans. When the patients were tested on a probe span task (typically thought to depend on phonological information) one of the patients, EA, showed worse retention in span tasks utilizing phonological information than in span tasks utilizing semantic information. The other patient, AB, showed the reverse pattern. Moreover, as would be predicted from performance on the span tasks, EA was more impaired on sentence repetition than on sentence comprehension, whereas AB was more impaired on sentence comprehension (for sentences whose semantic content exceeded a critical level) than on sentence repetition. The dissociation of semantic from phonological information in these patients is strong evidence for separable semantic and phonological components in short term memory.
Further evidence is provided by Martin and Saffran (1995), who investigated single word repetition in twelve brain-damaged individuals. These patients were found to have varying degrees of phonological and semantic impairment according to an evaluative test the authors used to index their abilities. The authors suggest that if phonological information cannot be maintained, as in the case of patients with phonological deficits, word repetition should be especially dependent on lexical and semantic representation; hence, repetition performance should be influenced by frequency and imageability. In contrast, these variables should have relatively little effect if phonological information is available for repetition. They also predicted that since recall of words across serial positions is differentially affected by different variables, patients with different deficits affecting these variables will show corresponding patterns of recall across serial positions. With their patients, semantic deficits should detrimentally affect repetition at the beginning serial positions, while a phonological deficit should affect repetition at the terminal positions. The results of their study in general supported their predictions. Primacy effects were positively correlated with semantic abilities, and recency effects were positively correlated with phonological abilities. As mentioned above, this suggests a reliance upon semantic information for those patients with a primacy effect, but no recency effect, and the reliance upon phonological information for those patients exhibiting a recency effect, but no primacy effect.

Taken together, the above evidence suggest that short term memory consists of not only multiple phonological components and articulatory
components, but lexical and semantic components, as well.

**Uses of Short Term Memory**

Concurrent with research defining the functional structure of STM has been an effort to identify the theoretical and practical significance of the components of short term memory for language processing abilities such as sentence comprehension, vocabulary learning, reading, writing and spelling.

**I. Sentence comprehension.**

Much recent research has focused on the possibility that phonological STM is crucial to sentence processing. It had been assumed that it is necessary to store phonological representations of the words of a sentence until they can be integrated to yield the sentence meaning. STM was thought to preserve order information which is assumed to be necessary for complete and accurate syntactic processing, especially of long and complex sentences (Vallar & Baddeley, 1984). Support for these assumptions comes from neuropsychological patients with very impaired memory spans who display difficulties with sentence comprehension (e.g., Caramazza, Basili, Koller, & Berndt, 1981; Saffran & Marin, 1975). The results from these studies have been interpreted to indicate that STM deficits affect these patients' ability to successfully process sentences, and especially syntactic information. However, a growing body of research now suggests that although span is clearly related to the retention of purely phonological material, it does not appear to be directly tied to sentence comprehension. The short-term memory patient, EA (introduced above), has a severely
reduced auditory span of two items but shows remarkably preserved sentence comprehension (Martin, 1993). In a study by Martin, (1993) EA displayed the typical pattern of performance on verbal material associated with deficits of phonological STM, namely, a severely reduced span, a phonological similarity effect for auditory (but not visual) material, a reverse modality effect, the lack of a word length effect, and a reduced or absent recency effect. When tested on materials that required verbatim recall, EA performed very poorly. However, when asked to judge the acceptability of sentences by detecting gender mismatches between pronouns and their referents, and to detect word order reversals over increasing sentence lengths, EA performed very well. These results suggest that syntactic processing is not dependent upon intact STM as measured by span tasks.

Vallar and Baddeley (1984) also reported that their patient, PV (described above), performed at a normal level on a syntactic comprehension test that included complex sentence structures such as reversible passives. In another study, Butterworth, Campbell & Howard (1986) described a developmental subject, RE, with impaired phonological processing and a reduced memory span. She was given a variety of tasks which tested her ability to syntactically analyze, remember and comprehend long and complex sentences, as well as tasks that tested sentence repetition. She demonstrated normal ability with syntactic analysis and sentence comprehension but was impaired in her ability to repeat sentences that she had comprehended, thus providing more evidence that a verbatim representation is not necessary to sentence comprehension.
It should be noted that because RE is a developmental case, the argument has been made that her sentence processing abilities may be the result of complex or unusual strategies that she has developed. A suggestion of this is found in her non-word reading. When asked to read 30 three-letter non-words aloud, she was able to pronounce 21 of them. However, her reading of these items was very slow, averaging about 3 s for each item, suggesting that she attempted to access the correct sounds by means of hunting for a similar lexical item, and coming up with a pronunciation of the non-word by way of analogy. Although these results suggest unusual strategic processes for reading aloud, it is harder to see what strategies might have been used for syntactic processing. That is, it is unclear how someone could develop and alternative set of processes that would handle all of the various structure of the English language.

The above studies suggest that while tasks that require verbatim representations of sentences are related to memory span, access to syntactic information does not appear to be related to span.

II. Reading.

Some theorists have suggested that during reading, visual information is converted to a phonological code which is maintained in short term memory until comprehension is achieved (Baddeley, Eldridge, & Lewis, 1981; Slowiaczek & Clifton, 1980; Levy, 1977) Articulatory suppression has been used to test this concept, with the assumption that the conversion of a visual code to a phonological code would be disrupted if the articulatory loop was engaged in production of irrelevant speech. If
reading requires phonological STM, then a detrimental effect of articulatory suppression on reading comprehension should be seen. Though such effects have been found, these studies have used a suppression task plus another task. Thus it is possible that the effects attributed to disrupted phonological recoding processes could instead be the result of a drain on general cognitive resources as a result of dual tasks, rather than a specific failure in phonological processing. In fact, when Water, Komoda, & Arbuckle (1985) analyzed the effects of several secondary tasks on reading comprehension using a statistical adjustment procedure to control for the general processing capacity required by the different secondary tasks, they found no detrimental effect on comprehension specific to secondary tasks that involved phonological coding.

Methods other than articulatory suppression have been used to investigate the role of phonological STM in reading. Coltheart, Laxon, Rickard, & Elton (1986) asked subjects to make acceptability judgments on sentences which either did or did not contain words that were homophones. Some of the homophones were appropriately used in a sensible sentence (haul the load), but others, while sounding like plausible words, were not appropriate (tie the not rather than tie the knot). Performance was worse for the homophone sentences than for the control sentences, but only with the anomalous sentences, suggesting that though phonological memory can be used, it may be limited to situations in which a checking process is required, as in the case of an anomalous sentence.

Further evidence relating to the importance of phonological STM to reading comprehension was provided by Martin, Wogalter, and Forlano
(1988) in an experiment investigating the effects of unattended speech on reading comprehension. Subjects were asked to read passages for meaning while listening to a background of nonword, random words, white noise, or a quiet background. Though they found an interfering effect of each of the background noises as compared to a quiet background, the random word background was much more disruptive to comprehension than was the non-word background. Though it had the same phonological characteristics as the word background, thus should have had obligatory access to phonological STM, the non-word background did not differ statistically from white noise in the amount of interference. This result would be hard to explain if reading comprehension relies on the maintenance and storage of a purely phonological representation of the sentences being read. It instead suggests that the interference observed was due to the semantic properties of the words, rather than the phonological properties.

Because readers have the ability to re-read confusing or ambiguous sentences, the above results are intuitively plausible--readers should not necessarily need to keep a verbatim representation of the sentence in STM, except in instances when the exact phonological representation might be important, such as when there is an ambiguous word or phrase. The eye movement studies that have investigated this issue tend to support this reasoning. Subjects do tend to reread ambiguous sentences. However, they do not reread the whole sentence, but instead go directly to the ambiguous word or phrase (Carpenter & Daneman, 1981; Frazier & Rayner, 1982).

The above results, as well as other recent research, tends to support
the immediacy of processing framework of sentence processing (Just & Carpenter, 1987). This framework assumes that lower (i.e., phonological) representations of words within a sentence are integrated into higher structures, such as syntactic and semantic structures, as quickly as possible, and to the highest degree possible. Once the higher structures are in place, the phonological information is discarded, thus making room for more incoming information. The data from patients with short-term memory deficits indicate that it is the syntactic structure and the semantic information that must be retained for sentence comprehension rather than the phonological information. For example, some studies have investigating the comprehension of patients on "garden path" sentences, which are sentences that lead the reader to mistakenly assume a particular syntactic structure or semantic interpretation. These studies have found that even patients with severely limited spans are able to read and comprehend such sentences quite well (Martin, 1993; Waters & Caplan, 1993). Such patients, with spans of 2 words or less, could hardly be expected to show good comprehension with these types of materials if the whole phonological representation must be kept in mind to achieve correct understanding.

Thus, the studies reviewed do not provide strong evidence for a large role of phonological STM in reading, except in cases where a backup representation may be needed, as in ambiguous sentences. However, the studies reported have been carried out for the most part with adult readers of normal competency. Among children, poor reading ability has been shown to coincide with limitations in working memory span and
phonological processing. Differences in recall among young readers have been found with a variety of verbal materials, including single words and sentences. Poor readers are less affected by phonological similarity in recall than are good readers, and have more difficulty performing tasks of phonological awareness (Shankweiler, Liberman, Mark, Fowler, & Fischer, 1979; Morais, Cluytens, & Alegria, 1984). In addition, it has been noted that these poor readers also have difficulties in object naming which appears to be the result of phonological confusions, rather than semantic or lexical problems (Katz, 1985). Though this evidence implicates deficient phonological short-term memory as a cause of reading problems, poor readers have also sometimes failed to comprehend complex spoken sentences accurately, leading some researchers to hypothesize that poor reading in these children may also be the result of poorly developed syntactic processing (Fletcher, Satz, & Scholes, 1981).

III. Language learning.

In the early memory models, STM was seen as necessary to long term learning. This idea was questioned when Shallice and Warrington (1970) reported that their patient, KF, displayed normal long term learning in spite of a severe STM deficit. Subsequently, other patients have been described that have specific short term memory deficits, yet whose long term learning appears to be fairly intact. These patients provide evidence that long term learning does not rely on short-term memory abilities. Though long term learning based on known words does not seem to depend on phonological short term memory, there is some evidence that this is not
the case for the learning of new phonological forms.

Recently, a number of researchers have explored the possibility that phonological short term memory deficits have consequences for acquisition of native vocabulary, as well as foreign language learning. The evidence supporting this possibility comes from subjects with acquired deficits as well as from developmental studies of children and from laboratory experiments on normal adults.

One of the first of these studies was conducted by Baddeley, Papagno, and Vallar (1988) on the stroke patient, PV, who displayed a very pure STM deficit. PV has a auditory digit span of two items and, like other patients of this type, shows no phonological similarity effect for visual presentation on memory span, but does show an effect with auditory presentation. In addition, she shows no word length effect nor an effect of articulatory suppression. The authors interpreted this pattern of results to indicate that PV has a very reduced phonological store, which they postulated might have consequences for long-term phonological learning. In order to test this possibility, PV was given a task in which she was to learn two sets of word pairs. One set was a list of meaningful word pairs in her native language, Italian, while the other set was a list of Russian words and their Italian translations. PV performed normally on learning the Italian word pairs, but was severely impaired on learning the Russian words. These results suggested that the ability to acquire language may rely on an intact phonological STM store.

This study was followed by a number of others which attempted to relate the phonological STM to language learning. QU, an eight year old
boy investigated by Gathercole and Baddeley (1990) was identified as having a digit span of three, yet displayed normal intelligence and long term learning. QU performed poorly on nonword repetition and word span, though he showed qualitatively normal phonological similarity effects and word length effects with shorter lists of words. However, with longer lists, these effects disappeared. This pattern of results has been taken to indicate that QU (and others displaying the same pattern) can and does make use of phonological coding with relatively easy tasks, but abandons that strategy when it becomes unreliable. QU was also tested on measures of vocabulary, syntax, and reading comprehension, and performed well below the average performance level for children of his age on all three, which is consistent with the idea that phonological short term memory is important to language learning.

Baddeley conducted another study of a developmental case (Baddeley, 1993), this time on a graduate student, SR. Though SR has superior intelligence, he displays a significantly reduced digit span (as compared to a group of fellow graduate students), but, like PV and QU, shows normal phonological similarity and word length effects. Though he performed well on tests of visual short term memory, he showed impairment on nonword repetition and his span for auditorily presented similar and dissimilar words and letters was impaired. With this pattern of results, SR was determined to have a specific phonological short term memory deficit, and was thus appropriate for testing the importance of auditory-verbal STM to language learning. SR was administered a foreign language learning test, similar to the one given to PV. He was given two
sets of word pairs to learn. One set of the pairs comprised unrelated English words, and another set were Finnish words and their English translations. SR performed as expected: he did very well on the English word pairs, but was impaired on the learning of Finnish vocabulary words, though he did learn a few. Interestingly, those few words were learned (by his account) using a semantic strategy, relating the Finnish words to the English translations by way of very elaborate associations. Again, these results support the idea that phonological STM is necessary to the learning of language. They also suggest that semantic strategies may be brought into play when phonological retention is impaired.

Other studies have been done on normal subjects. Papagno, Valentine, & Baddeley (1991) found that articulatory suppression (that is, continuously repeating an irrelevant speech sound) disrupted the learning of Russian words, but not native language word pairs for Italian subjects. Articulatory suppression has been shown to interfere with immediate serial recall, and to diminish or eliminate the phonological similarity effect in immediate recall of visually presented material, as well as remove the effects of word length in auditory and visual presentation (Baddeley, Lewis, and & Vallar, 1984). Because the phonological loop is considered to maintain information in STM by means of a subvocal rehearsal mechanism, articulatory suppression is assumed to interfere with the maintenance of phonological information in STM and to disrupt the phonological recoding of visual information. If under these conditions subjects are unable to learn new words, one interpretation would be that phonological STM is important for foreign language learning.*
Interestingly, in the Baddeley, et al. (1984) study, when English speakers performed the foreign language learning task (using English paired associates, and Russian-English translations) their results failed to replicate the effect of articulatory suppression on the learning of Russian words by Italian subjects. This was explained as a reflection of the much greater associative values of English to Russian words, as compared with Italian to Russian words, allowing for greater ease in employing semantic strategies. When the conditions of the experiment were changed so that the associative values of English words to the items to be learned were much lower (using nonsense words, and Finnish words), the decrement in learning under conditions of articulatory suppression was replicated. This suggests that while phonological short term memory is used for the acquisition of new word forms, it can be circumvented by the use of semantic strategies.

As another means of investigating the role of phonological STM in language learning, Papagno and Vallar (1995) assessed short term memory and word learning in a population of polyglots. They reasoned that if language learning has a relationship to STM, then polyglots should show superior performance in STM tasks, and further, the advantage would not be explained by differences in general cognitive skills. Their study compared polyglots to monolingual or bilingual controls on (1) tests

* It should be noted, however, that articulatory suppression could potentially affect many different levels of representation. It might interfere with rehearsal as claimed by Baddeley et al., but could also interfere with the formation of an articulatory representation. In addition the phonological forms generated internally or through hearing one's own speech might interfere with the phonological representation of the foreign words to be learned. Thus the exact locus of an effect under suppression is unclear.
assessing verbal short-term memory; (2) tests assessing the ability to learn non-words and familiar words in a paired-associate paradigm; (3) tests assessing general intelligence and visuo-spatial memory. The results showed that the two groups differed reliably on the STM tasks with the polyglots performing better than the controls. They did not differ on the visuo-spatial tasks, vocabulary knowledge in native language, nor on general intelligence. In the word learning tasks, both groups performed equally well with the familiar words, but, the polyglots performance with the nonwords was superior to that of the mono- and bilingual controls. The authors take these data to indicate that there is a relationship between short term memory capacity and language learning. However, another interpretation is suggested by the Papagno, Valentine, & Baddeley (1991) study, which is that with more languages to draw on, the polyglots have richer material to form semantic associations to aid in learning new language forms than do the controls. On this interpretation, one might expect to see a relationship between ability to learn new language forms and the richness of the native language or, more accurately, the ease of forming semantic associations between the native language and the language to be learned. Thus the relationship would be less one of capacity than one of associative abilities. In any case, it is not clear if Papagno and Vallar (1995) are suggesting that superior short term memory gives rise to polyglotism, or if polyglotism gives rise to superior STM.

These studies in general support the idea that phonological STM is important to learning new phonological forms. However, some of the results suggest that while phonological STM is very important to the
acquisition of new word forms, semantic and lexical factors also have a role.

IV. Dictation.

Many of the activities that students engage in require the transfer of auditory information into writing. Though in some situations the listener may be allowed time to respond to each word before receiving more auditory input (as in spelling tests), it is more common that one must receive auditory information and write simultaneously. As writing necessarily lags behind the auditory input, one would usually be writing something different than what one is hearing. Though very little research has been done demonstrating the involvement of short term memory in taking notes to dictation, it would seem necessary to be able to store and maintain an accurate representation of the incoming phonological information until the processing the previous information for meaning and translation into an orthographic code is completed.

Present Study.

In the present study, we investigate a phonological short-term memory deficit which was discovered in a healthy subject, BS, with no history of disability. BS has a normal digit span, but shows a striking deficit in some auditory short-term memory tasks. Deficits similar to his have been linked to poor learning of new phonological forms (Baddeley, 1994; Papagno & Vallar, 1995) and in cases of developmental deficits, to a deficiency in the acquisition of vocabulary and other language skills, including comprehension (Gathercole & Baddeley, 1990). In spite of his
deficit, BS has earned his Ph.D. in molecular biology, so it must be assumed that his deficit does not have dramatic consequences for his ability to learn new information. However, it is of interest to determine the consequence of his deficit. That he can learn new material is not in question, but does his deficit affect the speed at which he learns or comprehends new information? Is his learning affected by the modality of presentation? Is his reading comprehension of new material affected? Is he more than usually affected by interference or cognitive load? Which types of materials are difficult for him to process, and which are not? As the literature reported above indicates, there is considerable evidence that deficits in phonological short term memory lead to poor learning of new phonological forms. Thus, it is of interest to determine how individuals with phonological deficits manage normal, or even superior, learning. The study below was intended to replicate the previous findings reported on this topic, as well as provide substantiating evidence for the role of phonological, semantic and lexical involvement in short term memory. In the section that follows, the subject, BS, is described, and a brief account is given of the various tests used to rule out a low-level deficit. A series of experiments is reported that establishes his short-term memory performance profile. Then several experiments are described that sought to determine the consequence of his deficit for a number of different domains, including sentence comprehension, the learning of new words, reading and taking notes to dictation. These results are interpreted in light of current theories of short-term memory and language learning.
Biographical background and preliminary testing.

The subject of this study, BS, is a 33 year old male. He has a doctorate in molecular biology. His physical health is excellent. He has no known deficits in audition, speech or comprehension. In all respects BS appears to be completely normal. He was identified as possibly having a short-term memory deficit when serving as a volunteer normal control for a spelling recognition experiment (i.e., given individual letters in sequence, the subject has to report the word that the letters spell). In this task his performance with visually presented letters was comparable to that of the other control subjects, but with auditorily presented letters his performance was far inferior. The possibility of a low-level hearing defect was ruled out by a standard audiometer hearing test. BS was given a test of (auditory) minimal phoneme pairs discrimination in which the non-matching pairs differed by a single phonetic feature (e.g., "ra-la" had to be identified as a non-matching pair, as opposed to "la-la"). He was also given an auditory lexical decision task, in which the words differed from the non-words by a single phoneme (e.g., "blickle"). In both of these tasks he performed nearly perfectly. On the WMS-R, his performance on the visual memory task was 97% in the immediate test and 93% on the delayed. On the WMS-R test of logical memory, which is a test of memory for a spoken story, he tested at 74% on the immediate and 94% on the delayed test. In the present study he was given a number of tests of short-term memory, which establish his performance deficit profile.
SHORT TERM MEMORY TASKS

I. Tests of Span

Memory span has been used to predict performance on a variety of tasks and activities thought to require the use of short term memory. Recent research has demonstrated that though span may predict performance on certain types of tasks, it is not necessarily directly related to all tasks utilizing working memory. For example, though span does seem to predict subjects' verbatim memory of sentences, it does not predict their ability to comprehend sentences. Reduced span has been associated with individuals that have phonological short term memory deficits, with a pattern of greater span for visually presented items than for auditorily presented items. In addition, most patients with this type of deficit have great difficulty with non-word stimuli. Though on the standard WAIS-R auditory digit span test BS had a span of 8 with both trials correct, and a highest correct trial span of 9, his ability with other verbal stimuli was not known. In order to determine if BS fit the profile corresponding to a phonological short term memory deficit, he was administered tests of memory span using rhyming and non-rhyming letters, words and non-word stimuli as well as a test of span for words that were varied for frequency and imageability. Stimuli which are phonologically confusing, such as those in the rhyme tasks, may be more difficult to maintain as phonologically distinct representations because the loss of a single piece of phonetic information could render rhyming words as indistinguishable from one another, whereas non-rhyming words have more than a single phonetic feature on which they differ, thus would remain distinct even with
slightly degraded phonological representations. Thus, if BS has trouble maintaining intact phonological representations, but is able to utilize semantic information efficiently, one would expect him to recode information in terms of semantics rather than phonology. Therefore, variables that affect the semantic properties of words, such as frequency and imageability should have an effect on his performance on tasks such as repetition. However, if he is prevented or discouraged from using semantic properties, such as in the case of non-words or in words of low frequency and imageability, one would expect his performance to suffer.

Three experiments were administered to BS to test these predictions. The first of these, Experiment 1, is a group of span tasks, utilizing rhyming and non-rhyming stimuli, as well as word and non-word stimuli. The second, Experiment 2, tests BS's ability to repeat non-words of varying syllable and list lengths, and finally, Experiment 3 investigates the effect of frequency and imageability on BS's word repetition.

Experiment 1: Repetition span tasks

Method

Materials and procedure. All of the span tasks followed the same general procedure. A set of 10 items were identified from which the stimuli for the trial were drawn. A trial consisted of the presentation of a string of items at a rate of one item per second. At the end of each trial BS was to repeat the string of items in the correct order. In the visual condition, BS viewed the items as they were presented on a computer screen. In the auditory condition, the experimenter read the items aloud as they appeared on the computer screen (which was not seen by BS). There
were 10 blocked trials for each type of stimulus. In the rhyming letter condition, the items were drawn from the letter set (b,c,d,g,p,v,t), and in the non-rhyming condition, from the letter set (f,k,q,r,x,w,z). The rhyming word set (cot, bought, talk, taught, got, awe, paw, dock) was similar to the non-rhyming word set (bright, tale, pal, thought, goat, cat, dock, owe) in orthography, syllable length, and frequency. The session started with a list length of 3 items, and increased by one item until BS failed to repeat 50% of the trials correctly.

Ten Rice University undergraduates served as normal controls in this experiment.

Results and discussion.

The results for list length 5, the maximum list length attained by BS, are show in Table 1 in terms of words correct (without respect to order). With visual presentation, BS performs at a level comparable to the controls, and within the normal range. However, with auditory stimuli, BS's performance is well below the normal range, except for non-rhyming letters. Collapsing across the different types of lists, BS shows a marked advantage in performance with visual stimuli as compared to auditory stimuli, the reverse of the control subjects' pattern (Figure 1).
Table 1

Repetition span task: Mean words correct in correct position of list length 5 of BS vs. Controls and Range of normal controls as compared to mean of BS.

<table>
<thead>
<tr>
<th>Stimuli</th>
<th>VISUAL (Mean)</th>
<th>AUDITORY (Mean)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Letters</td>
<td>Rhy-letters</td>
</tr>
<tr>
<td>Control</td>
<td>4.7</td>
<td>3.9</td>
</tr>
<tr>
<td>BS</td>
<td>4.2</td>
<td>3.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stimuli</th>
<th>VISUAL(RANGE)</th>
<th>AUDITORY(RANGE)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Letters</td>
<td>Rhy-letters</td>
</tr>
<tr>
<td>Control</td>
<td>4.2-5.0</td>
<td>2.2-5.0</td>
</tr>
<tr>
<td>BS</td>
<td>4.2</td>
<td>3.8</td>
</tr>
</tbody>
</table>

A characteristic of the word stimuli may explain BS's surprisingly poor performance in the non-rhyme word condition as compared to the non-rhyming letter condition. Because many of the words in the non-rhyme set were chosen to be orthographically similar to the rhyme set, they contained many phonological similarities as well. It may be that even internal phonological similarity, excluding rhyme, causes problems for BS.
in the non-rhyme set of words. This situation, of course, would not exist
in the non-rhyme letter set.

Figure 1
Repetition span task: Auditory vs. Visual presentation condition at list
length 5.

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Repetition span tasks: visual vs. auditory presentation

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In many of the cases of acquired phonological short term memory
deficits, there is an absent (or reduced) phonological similarity effect for
visual, but not auditory stimuli. BS shows an effect of phonological
similarity in both the auditory and the visual conditions, as do the normal
controls. However, the controls display approximately similar degrees of
the effect in both the auditory and visual conditions, whereas BS shows a
markedly greater effect in the auditory condition as compared to the visual condition. This result is similar to some cases of developmental phonological short term memory deficits which have been previously described (Campbell & Butterworth, 1985; Gathercole & Baddeley, 1993). The larger than normal effect with auditory presentation has been interpreted to indicate that these individuals have the ability to use phonological coding, but decline to do so when it becomes unreliable as in the phonologically similar conditions. (The normal size effect with visual presentation is difficult to explain under this assumption, however). In addition, BS displays a reverse modality effect, which is also consistent with previously described cases of phonological short-term memory deficit, and has to do with the idea that performance in the visual modality is enhanced by the use of visual or orthographic codes, whereas in the auditory modality, no such help is available.

Experiment 2: Non-word repetition and effects of syllable length.

Method

Materials and Procedure: One-, two-, and three-syllable non-words were presented in list lengths of 2 and 3 items. The experimenter read the string of non-words aloud at a rate of approximately 1 word per s. Immediately after the final item had been presented, the subject then repeated the string back to the experimenter. There were 10 blocked trials of each condition (one-syllable/2 items; two-syllable, 2 items; three syllable, 2 items; one syllable, 3 items; two-syllable, 3 items; three syllable, 3 items). No item appeared more than once.

The word stimuli were similar in that they were one-, two-, and
three-syllable words, but the list length started at 4 items and continued until strings of 6 items of each syllable length had been presented. In addition, there were only 5 trials each of the word stimuli.

The four age- and education-matched controls were tested only on the non-word stimuli.

Control data for the word repetition task was obtain from Rice undergraduates.

Results and Discussion

The results are presented in terms of percentage of lists correct and are shown in Table 2. For comparison, mean percentages for control subjects are reported in parentheses next to BS's values. As can be seen in Table 2, with non-words BS performs below the average of the controls at every syllable- and list length and is below the range of the controls. In contrast, his word performance is generally equal to or better than the controls, with the exception of a syllable length of 3 in which he appears to be somewhat impaired with 4- and 5- item strings. However, with 6-item strings, he seems to have developed some strategy as an aid in recall as his performance is far better than that of the average of the controls.
Table 2

BS's word and non-word repetition: % lists correct by syllable length and list length. Normal means are in parenthesis.

<table>
<thead>
<tr>
<th>List Length</th>
<th>Non-Word Repetition</th>
<th>Syllable length</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>50(95)</td>
<td>30(92.5)</td>
</tr>
<tr>
<td></td>
<td>(range: 90-100)</td>
<td>(range: 80-100)</td>
</tr>
<tr>
<td>3</td>
<td>40(87.5)</td>
<td>20(80)</td>
</tr>
<tr>
<td></td>
<td>(range: 70-100)</td>
<td>(range: 60-90)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>nt</td>
</tr>
</tbody>
</table>

Word repetition

<table>
<thead>
<tr>
<th>List length</th>
<th>syllable length</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>60(90)</td>
</tr>
<tr>
<td></td>
<td>60(83)</td>
</tr>
<tr>
<td>5</td>
<td>60(58)</td>
</tr>
<tr>
<td></td>
<td>60(65)</td>
</tr>
<tr>
<td>6</td>
<td>60(58)</td>
</tr>
<tr>
<td></td>
<td>60(52)</td>
</tr>
<tr>
<td></td>
<td>100(32)</td>
</tr>
</tbody>
</table>

A reduced ability to repeat non-words is expected if the phonological representation used is impoverished or inaccurate. Non-words, having no semantic representation, would not allow for repetition or recall based on a semantic/lexical strategy, hence performance would be impaired, as it is with BS. In the next experiment, a closer look is taken at the variables relating to dependence on phonological or semantic factors. Specifically, for a person relying on semantic or lexical factors, words that are low in frequency and in imageability should be more difficult to recall than words
that are high in frequency and imageability.

Experiment 3: Repetition of words varying in frequency and imageability.

Method

Materials and Procedure: The lists of words that were used varied in imageability and frequency. These materials have been described in detail in N. Martin & E. Saffran (1997). In general, the lists comprised four types of words, high frequency-high imageability (HF-HI), low frequency-high imageability (LF-HI), high frequency-low imageability (HF-LI), and low frequency-low imageability (LF-LI), and were arranged into lists that were either 4 items long or 5 items long. There were 10 lists of each of the 4 word types at each list length. The order of the type of word varied randomly. The subject was read a list of words, and then immediately attempted to repeat it in the correct order. Scoring was done three ways: (a) number of lists entirely correct (b) number of words per list repeated in the correct order, and (b) number of words per list repeated correctly regardless of order.

Control subjects were 19 Rice undergraduates.

Results and discussion.

BS did quite well on the 4-item lists, repeating correctly 32/40 (80%) of the lists with an average of 3.8 items per list correct. However, his performance on the 5-item lists was dramatically reduced: BS correctly repeated only 6/40 (15%) 5-item lists, with an average of 3.25 items correct per list. All further discussion will refer to the data from the 5-item lists, unless otherwise specified.
It was expected that with a phonological short-term memory deficit, BS would have to rely on semantic and lexical factors to support repetition, therefore, his performance on the LF-LI words should be much poorer than on the other word types, which was not the case as can be seen in Figure 2. There were no significant differences in the number of words recalled per list among the different word types, F(3,36) = .304, p = .812. When compared to the performance of control subjects, BS appears to be only mildly impaired. When recall is scored in terms of words in the correct position, his performance was just within 2 standard deviations from the controls' mean, shown by the error bars in Figure 2. Thus it cannot be claimed that he demonstrates an notable impairment in this experiment. It should be pointed out, however, that these data are with lists of 5 items, at which span BS has previously done pretty well. In a different experiment (described later) investigating repeated list learning using similar materials, BS shows a much greater impairment when list length is increased to 6 items.

The other finding of interest is the absence of a recency effect for any of the word types, except the HI-HF words, shown in Figure 3a. Even in the HI-HF lists, the effect was very reduced. By contrast, the control subjects' data from 6-item lists shows a recency effect in all list types. This is displayed in Figure 3b. These data are consistent with the claim made by N. Martin & Saffran (1997), that patients relying on lexical-semantic factors should show an advantage in recall for the primacy items of a list, but not the recency items.
Figure 2
Frequency and imageability repetition span task, 5-item lists, words per list recalled by word type regardless of position (Any position) and in the correct position (Correct position).
Figure 3a

Frequency and imageability repetition span task: Words correctly repeated by BS in any position by serial position of presentation and word type.

Recall by position/word type, BS

![Graph showing recall by position/word type for BS with serial position on the x-axis and proportion of words recalled on the y-axis. Different lines represent different word types and presentation conditions.]
Figure 3b.
Frequency and imageability repetition span task: Words correctly repeated by controls in any position by serial position of presentation and word type.

![Graph showing recall by position/word type controls](image)

Finally, Figure 4 allows for a direct comparison of BS's performance as a function of the method of scoring, either crediting all words recalled correctly in any position or only those words recalled in the correct position. These data indicate that though some of errors committed by BS are errors of order, they do not account for a large proportion of his errors in this task.
Figure 4.
Repetition span task: total words of list length 5 recalled by serial position collapsed across all word types. The two lines represent the two methods of scoring: "correct" is words recalled in the correct position, "any" is words correct without regard to position.

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I. Tests without production

The previous tests indicate that BS has a deficit in some aspects of short-term memory. His performance on the repetition span tasks demonstrated that he has better memory for visual materials than for auditory materials, a phonological similarity effect that is qualitatively normal for visual materials, but exaggerated for auditory materials, and an
absent or reduced recency effect. This pattern of performance has been associated with a phonological short-term memory deficit. The locus of the deficit cannot be determined from his performance on these tasks because he was required to produce written or verbal responses. Thus his poor performance could be the result of difficulties with speech production (or writing), rather than with short term memory. For example, if BS has difficulty with the articulation of words, then his spoken responses may be very slow, so while he is concentrating on producing a word, he may forget others. However, if he is not required to produce a list of words, but rather must make only a minimal response (e.g., "yes" or "no"), and he still shows a deficit, then it can be more reasonably attributed to a problem with the coding or storage of phonological information, rather than with production.

The following tasks were given to BS in order to discriminate among these possibilities. The tasks are similar to the previous ones in that they are tests of span, however, rather than having to produce the entire string, the subject has only to respond "yes" or "no" to a judgment involving the string.

If the deficit is the result of faulty storage of phonological information, conditions of output should not affect performance. That is, if the information is degraded only during storage, no manipulation at the time of test should affect performance further. Performance should be uniformly poor regardless of whether the output is spoken, written, pointed to, or a minimal response. If, however, if BS has a problem with production, then conditions which require him to write or speak should be
more difficult, regardless of input modality.

Experiment 4: *Probe span tasks*

**Method**

**Materials and design.** The experiment consisted of two probe tasks, semantic and rhyme, and for each task two presentation conditions, visual and auditory. In the semantic condition, lists were constructed of unrelated concrete nouns that were similar in frequency and word length. List length varied, starting with a length of 3 and increasing to a length of 10. A trial consisted of the presentation of a list and then a probe word. In half of the trials, a probe word was used which was semantically related to one of the items in the list (the target item). For the other half of the trials, the probe word was unrelated to the items in the list, thus these trials had no target. The subject was to say "yes" if he detected a target, and "no" if he did not. Target position was varied so that it occurred in each position in the list across the trials. The presentation order of the trials within a list length condition was varied randomly.

In the rhyme condition, the lists were constructed in a similar manner, with the target word dissimilar to other words in the list, but rhyming with the probe word. As in the semantic condition, a target was present in only half of the lists, and was varied with respect to position and presentation order.

BS was first tested on the semantic probe task, with trials within the visual and auditory conditions blocked. He was then tested on the rhyme probe task in the auditory and visual conditions.

The control data for this experiment is from 30 Rice undergraduates.
who were tested only in the auditory condition, and six elderly adult subjects, who had performed the semantic and rhyme probe tasks in the auditory condition as control subjects for a different study. In addition we included one young adult who volunteered to serve as an age and education matched control for BS in this study.

**Procedure:** The beginning of a trial was signaled by an asterisk in the middle of the screen in the visual condition, or by the experimenter saying "Ready?" in the auditory condition. Words of a list were presented on the computer one at a time with a presentation rate of 2 s per item in both the visual and the auditory condition. A tone signaled the end of the list. The probe item was then presented. The subject was instructed to indicate whether the probe word was related to any word in the list (in the semantic condition), or if the probe word rhymed with any word in the list (in the rhyme condition). The same procedure was followed for both the visual and the auditory conditions, except in the auditory condition the subject did not view the stimuli. Instead, the list words and probe were read aloud by the experimenter as they appeared on the computer screen. Testing commenced with lists which were 3 items long. Upon successful completion of the task, each list length was increased by one item until the error rate was greater than 25% for a particular list length, at which time testing was discontinued.

**Results**

Because six-item lists were the maximum obtained in three of the four conditions, only these data are reported. With the 6-item lists in the auditory presentation condition, BS responded correctly to 79% of the
trials in the semantic task, but only 50% of the trials in the rhyme task. In contrast, as seen in Table 3, the undergraduate controls, the elderly and student control subjects and the age matched control subject showed comparable levels of performance in the semantic and rhyme tasks, and in fact, the elderly controls showed somewhat better performance in the rhyme task as compared to the semantic task, the reverse of the pattern displayed by BS. Although with auditory presentation, BS is well within the range of the controls on the semantic task, he is considerably below the range in the rhyme task.

With visual presentation, BS responded correctly to 83% of the trials in the semantic task, and to 84% of the trials in the rhyme task. This pattern was similar to the pattern displayed by the age matched control, who had comparable performance in the semantic and rhyme tasks. No data were collected for the undergraduate controls nor for the elderly controls in the visual condition.
Table 3

Probe span tasks: percentage correct of responses at span 6 for rhyme and semantic probe tasks in the auditory and visual presentation conditions. (BS and control subjects).

<table>
<thead>
<tr>
<th></th>
<th>Rhyme task:</th>
<th>Semantic task</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Auditory</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BS</td>
<td>50</td>
<td>79</td>
</tr>
<tr>
<td>student controls</td>
<td>85</td>
<td>77</td>
</tr>
<tr>
<td>range: 71-100</td>
<td>range: 58-96</td>
<td></td>
</tr>
<tr>
<td>elderly controls</td>
<td>83</td>
<td>72</td>
</tr>
<tr>
<td>range: 71-92</td>
<td>range: 63-87</td>
<td></td>
</tr>
<tr>
<td>age matched control</td>
<td>91</td>
<td>90</td>
</tr>
<tr>
<td><strong>Visual</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BS</td>
<td>84</td>
<td>83</td>
</tr>
<tr>
<td>age matched control</td>
<td>87</td>
<td>84</td>
</tr>
</tbody>
</table>

Discussion

Because minimal output was required in these tasks, BS's impairment in the auditory rhyme condition cannot be attributed to difficulties with production. BS's poor performance in the auditory rhyme condition is consistent with a deficit in retaining phonological codes in short-term memory. His good performance in the auditory semantic task indicates that he can activate from the phonological level and maintain semantic information at a normal level. BS's performance with visual presentation appears normal for both tasks. Again, for the semantic task, he can activate semantic information from an orthographic code and retain it at a normal level. His good performance in the visual rhyme condition is somewhat more difficult to explain, assuming a deficit in phonological
storage. One possible explanation would be that he performed this task on the basis of orthographic codes rather than phonological codes. This would have been possible given that the task was not designed to control for orthographic overlap between the probe item and the rhyming list item. That is, visually dissimilar rhyming trials (e.g., eight, mate) were not specifically selected for inclusion in this task.

III. Non-Verbal tests of memory:

The short-term memory tests administered to BS thus far have all involved verbal materials. Further, though he performed well on the semantic probe task, it is possible that some of his poor performance in other areas might be the result of an attention deficit. The present tests were administered to determine if he had a general short-term memory impairment or difficulties in maintaining attention, rather than a specific problem with verbal materials. Two tests are described: one which tested his memory for non-verbal acoustic material, and the other which tested his non-verbal visual memory.

Experiment 5: Non-verbal sounds tasks.

Method

Materials and Procedure: A set of non-verbal auditory stimuli were created and recorded as sound resource files. The stimuli were sounds that could not be readily labeled or identified with a nameable object. Examples of typical stimuli are a marble rolling around inside a can, a toy car pushed across a rough wooden plank, or air slowly let from a balloon to make a squeaky noise. As a check of ease of labeling the sounds and to ascertain that the sounds were distinct, 5 people were recruited to listen to
the sounds, and asked to try to identify them. One of the original 20
sounds was correctly labeled by 3 of the testers and was therefore replaced.
Strings of items were constructed by the random selection of stimuli from
the entire set for each trial. The beginning list length was 3 items long,
and increased by 1 item until the subject was correct on only 75% of the
trials, or until the maximum list length of 10 trials was reached. There
were 10 trials at each list length.

The subjects' memory for the sounds was tested in two ways: a
matching task and a identity probe task. In the matching task, subjects
heard a string of the sounds, a short pause, and then another string of the
same sounds either in the same or in a different order. They were to
determine if both strings matched. In the identity probe task, subjects first
heard a string of sounds, then a pause, then a single sound. They had to
determine if the single sound was identical to any sound in the string.

Control subjects: Five adults approximately matched in age and
education were control subjects for this experiment.

Results and discussion:

*Non-verbal sounds matching task.* BS responded correctly to 100%
of the trials at list lengths of 3 and 4, 80% at list length of 5, and 67% at a
list length of 6. This is well within the range of the normal controls
(range of controls at list length 3 was 50-100%; list length 4, 50-87%; list
length 5, 50-100%; list length 6, 55-95%).

*Non-verbal sounds identity task:* BS correctly identified the
presence or absence of the probe stimulus in 100% of the trials of list
length of 3, 4 and 5. He was correct on 85% of the trials of list length 6,
100% at list length 7, and 63% at list length 8. This again was well within the range of the normal controls (range of controls at list length 6 was 67-100%; list length 7, 86-100%, and list length 8, 50-87%).

It is clear from these results that the cause of BS's poor performance in the auditory short term memory tasks cannot be attributed to the inability to retain acoustic information. In spite of his relatively poor performance in previous auditory verbal tasks, he did as well as the normal controls in these non-verbal auditory tasks.

Experiment 6: *Non-verbal visual span task*

Method

**Materials:** Stimuli were composed of a mixture of 1 in. black and white squares arranged in rows. Each block was only 2 squares vertically, but the number of squares in the block was varied horizontally according to span length. Thus a span of 2 had a block of squares that was 2 X 2, a span of 4 had a block of squares that was 2 X 4, and so on to the maximum span of 12 squares. The pattern of black and white squares was determined randomly with an equal number of each color square at each list length condition. There were 4 trials of each span length. A trial consisted of the presentation of a block on the computer screen for 3 s, a 2 s pause, then recall of the block pattern on a response sheet. The response sheet was a printed outline of the block with none of the black squares filled in, so that at the time of recall, the subject reproduced the block pattern by filling in the blank squares.

Five adults approximately matched in age and education were control subjects for this experiment.
Results

BS correctly reproduced all trials up to a span length of 12. This was as good or better than the controls. This suggests that his visual memory for non-verbal material is unimpaired.

Discussion

His performance with non-verbal materials indicate that BS does not have a general impairment of short-term memory, nor an attentional deficit. Rather, it seems that his short-term memory problems are specific to verbal materials.

IV. Supraspan tests of short-term memory

BS has displayed a fairly clear pattern of performance with the span tasks, that is, the pattern that has come to be associated with a phonological short-term memory deficit. However, the underlying cause of his problem is still less than clear. Though it is clear that his impairment cannot be attributed to language production, his problems could by caused by the rapid loss of phonological information, or by interference. In order to gain a better understanding of his deficit, we administered recall tasks of supraspan lists. Some effects of lexicality have been shown to be present in supraspan lists that are not present in shorter lists. Notably, it appears that frequency effects are limited to all but the last two list positions in supraspan lists (Watkins & Watkins, 1977). It was expected that BS would again show an advantage in recall of visually, as compared to auditorily presented lists, as well as a reduced or absent recency effect. In addition, the use of supraspan lists allowed for the analysis of error data which would hopefully give more information about the source of BS's problems.
BS was given two recall tasks: immediate free recall of random words with both visual and auditory presentation, and also serial recall of random digits with visual presentation. Because of a computer error, the serial digit recall task was accidentally performed three times.

Experiment 7: Immediate free recall

Method

Materials. For the free recall task, lists were constructed of 200 common one- and two-syllable words taken from the Toronto Word Pool. Lists were 10 items long and there were 10 lists in all for each of the auditory and visual modalities.

Procedure. Items were presented one at a time, each for 2 seconds. In the auditory conditions, the experimenter read the items aloud from the computer screen. In the visual condition, the subject viewed the items directly from the computer screen. After presentation, a tone sounded to signal the end of the trial and the subject then immediately recalled the items by writing them on a response sheet. In the free recall task, the subject was free to recall the words in any order, but was to write the word on the numbered response sheet in its correct position.

A group of 4 graduate student volunteers of approximately the same age and educational background as BS served as normal controls.

Results and discussion.

Free Recall. Results of the free recall are shown in Figures 5a and 5b. Words were scored as correct in two different methods: (1) correct recall of words that appeared on the list, regardless of position; and (2) recall of words in their correct position. There were no significant
differences in the methods of scoring so only the data scored by method (1) will be reported.

In contrast to his performance on the repetition task, BS showed evidence of a recency effect with both the visual and the auditory presentation modalities. This can be explained by the fact that upon the completion of the presentation of the list to be recalled, BS immediately wrote down the last one or two items that were presented. Thus, in the auditory condition, his recency recall was very similar to the controls. However, recall of the rest of the items in the list was somewhat depressed as compared to the average of the controls, which suggests that his ability to maintain these items was reduced. In the visual condition, both the primacy portion of the curve and the recency portion are reduced as compared with the controls, and while recall in the middle portion of the curve is more similar to that of the controls, it is still reduced. These data are shown in Figure 5.
Figure 5
Free recall of auditorily presented items, BS vs. Controls and free recall of visually presented items, BS vs. Controls
In terms of average number of words recalled irrespective of position, BS was below the range of the controls for auditory presentation and was just within their range for the visual presentation condition. These data are displayed in Table 4.

Table 4
Immediate free recall: Mean number of words recalled by presentation modality.

<table>
<thead>
<tr>
<th></th>
<th>Auditory</th>
<th>Visual</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS</td>
<td>4.1</td>
<td>4.1</td>
</tr>
<tr>
<td>Controls</td>
<td>5.67(range = 3.8-6.7)</td>
<td>5.35(range = 4.5-6.1)</td>
</tr>
</tbody>
</table>

Also counter to his previous performances, BS failed to show a reverse modality effect, or indeed, any sort of modality effect: the mean words recalled in each of the auditory and the visual presentation condition was 4.1 words. However, three of the four controls showed a reverse modality effect, with recall of visually presented material superior to that of auditorily presented material. These data are not particularly informative as to the nature of BS's deficit; however, the analysis of the error data was somewhat more illuminating.

Error data. The most striking observation in the error data is the discrepancy of the number of errors (other than omission errors) committed by BS as compared to the normal controls. In the visual mode,
the controls made 4 substitution errors in all, that is, each subject on average made one error. In the auditory mode the substitution error rate was even lower, with 3 errors total (0.75 errors per subject) across all subjects. All but one of the errors in both modalities were phonological errors, the exception being an intrusion from a previous list. In contrast, BS, in the visual mode, made 3 substitution errors, of which one seems to be semantic ("enough" for "amount"), and the other two intrusions from the previously presented auditory stimuli. Regarding these latter two errors, it is not possible to distinguish visual similarity from phonological similarity ("odor" for "only") and ("grateful" for "gracious"), further, it is possible to interpret one of them as having a semantic relationship to the target as well. In the auditory mode, BS committed 8 substitution errors, all of which were phonological in nature (see Table 5). Although substitution errors are commonly phonological, this normally occurs equally in both the auditory and the visual modalities, as is seen in the error data of the control subjects. BS, however, not only has different errors rates in the auditory and visual modalities, but it is possible that the type of substitutions are different in kind. The data may be interpreted to indicate that BS uses different strategies with different modalities. This interpretation is supported by BS's own account. He volunteered that the visual condition was easier because he was able to construct a "story-line" with the words. In the auditory condition, he reports that he tried to say the words "over and over", indicating an attempt to rehearse the material, though apparently this strategy was not entirely successful.
### Table 5:

**BS's substitution errors in auditory and visual free recall**

<table>
<thead>
<tr>
<th>TARGET</th>
<th>RESPONSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual</td>
<td></td>
</tr>
<tr>
<td>odor</td>
<td>only</td>
</tr>
<tr>
<td>grateful</td>
<td>gracious</td>
</tr>
<tr>
<td>amount</td>
<td>enough</td>
</tr>
<tr>
<td>Auditory</td>
<td></td>
</tr>
<tr>
<td>singer</td>
<td>finger</td>
</tr>
<tr>
<td>minute</td>
<td>mimic</td>
</tr>
<tr>
<td>fairly</td>
<td>barely</td>
</tr>
<tr>
<td>pasture</td>
<td>pathway</td>
</tr>
<tr>
<td>accord</td>
<td>apple</td>
</tr>
<tr>
<td>salute</td>
<td>odor</td>
</tr>
<tr>
<td>ladder</td>
<td>latter</td>
</tr>
<tr>
<td>apart</td>
<td>heart</td>
</tr>
</tbody>
</table>

Experiment 8: *Serial digit recall.*

**Method:**

The method was similar to that of the free recall task, except the digits were recalled in serial order, and presentation was in the visual modality only (as earlier described, BS's performance had been already established with auditorily presented materials). As noted above, BS mistakenly repeated the entire task three times before the experimenter realized the redundancy. However, not to throw away perfectly good data,
all the data were scored and analyzed. This was done by collapsing across all three sets, as well as scoring each set separately.

Results and discussion.

When the serial digit recall data are collapsed across all three sets of data, the pattern is that of a fairly normal serial position curve, except for a reduced recency effect. However, when the three sets are analyzed separately, as seen in Figure 6, an interesting pattern emerges.

Figure 6
Serial digit recall: mean number of items recalled by BS according to serial position in Test 1, 2, and 3 (10 trials in each test).

In the first set of the digit serial recall (and the only data that would have been analyzed had the mistake in presentation not occurred), there is no
evidence of a recency effect. In fact, there is a negative recency effect in that the terminal items are recalled with less probability than items from the middle positions of the curve. In the second set, a recency effect is evident, though reduced; and in the third set, a fairly normal recency effect has appeared. These data may be interpreted to suggest that BS does indeed have problems recalling items based on phonology, as in the terminal list items of the serial position curve. However, with practice, he is able to quickly develop a strategy to help compensate for this deficit.

V. Interference tasks.

Some theorists have presented models of short-term memory which attribute failure to remember to interference (Nairne, 1990), in contrast to models of short term memory that attribute the loss of information to poor encoding or to decay of activation. By Nairne's account, probability of recall is related to the distinctiveness of one item from another within a short-term buffer. Distinctiveness is computed on the basis of the number of overlapping features of the items within the buffer. Thus this model credits the loss of information to interference, rather than to a decline in activation level. One possible explanation of BS's pattern of performance is that with auditory stimuli he experiences more than average interference from other stimuli that may be presented. If this is so, then the more similar the stimuli within the short-term buffer, the worse will be memory performance. Thus, very different stimuli, such as non-verbal shapes, should interfere very little with his memory performance, while very similar stimuli, such as verbal stimuli with a high degree of overlap to the
target stimuli should cause a much greater decrement in memory performance. By Nairne's model, this should be true for all subjects, but, if BS has trouble maintaining distinctiveness among stimuli, his performance should be affected even more than is the performance of the controls. To test this subjects performed a free recall task in which the presentation of a list was followed by either a verbal discrimination task (lexical decision) or an object discrimination task prior to recall.

Experiment 9: Interference tasks

Method.

Materials and procedure: This experiment comprised two tasks, one with auditorily presented items, and the other with visually presented items. Except for the modality of list presentation, the two task procedures were the same in all regards.

In this experiment 300 words, rated to be high-to-moderate in abstractness, were arranged into 30 lists (test lists) of 10 words each. Of these, 15 lists were used in the auditory task, and the remaining 15 lists were used in the visual task. These 15 lists for each task were divided into 3 sets of 5 lists. One set of 5 test lists was used for each of the distractor conditions (spatial, written, and spoken) described below. To match the test lists, another set of lists (distractor lists) was composed in which approximately half the items in each list were non-words created to contain a large proportion of phonemes that overlapped with the corresponding test list. The other half of the items in each list were random words of moderate abstractness. These words and non-words were used for lexical decision. In addition, a set of figures was used in which some of the
figures were 3-dimensionally possible, and some were not. These items were arranged into 15 "lists" of 7 items each. These items were used for object discrimination.

The basic procedure consisted of the presentation of a test list of words, then an intervening distractor task, then free recall of the test list. The test list was presented one word at a time at a rate of 1 word per s. After the test list had been presented, there was a 2 s interval, then either a single tone sounded to alert the subject to look away from the screen (in the auditory distractor condition) or two tones sounded to alert the subject to look at the screen (in the visual distractor conditions). The subject then performed the distractor task which could be one of three tasks: (1) a lexical decision task in which the subject had to decide if the word seen on the computer screen was a real word or a nonsense word, (2) a lexical decision task in which the subject had to decide if a word heard was a real word or a nonsense word, or (3) a task in which the subject had to decide if the object viewed on the computer screen could be a real 3-dimensional object or not. Each distractor task was 7 items long, with each item (in the visual conditions) presented for 1.5 s and a decision made immediately after each item. Subjects were instructed to make their decision as quickly as possible, but were not given a time limit. The distractor task conditions were varied randomly, but the test list presentation condition, auditory or visual, was blocked.

Four age and education matched adults served as controls in this experiment.
Result and discussion:

BS showed the now familiar advantage for visual presentation (of the test lists) over auditory presentation, $t(28) = 2.29$, p = .03, when collapsed across distractor conditions. But this advantage appears to come from the spatial and written distractor conditions. However, only in the written distractor condition was the difference significant, $t(8) = 2.63$, p = .03. As can be seen in Figure 7, the spoken distractor disrupted recall equally in the auditory and visual conditions. Although it appears that the spoken distractor in the visual presentation condition interfered with recall more than the written and spatial distractors, these differences were not significant by t-test (spoken vs. written, p = .11; spatial vs. spoken, p = .45). (see Table 6).
In contrast, the controls showed no significant difference between the auditory and visual presentation conditions, $F(1,3) = 1.42, p = .319$. Among the distractor conditions there were no significant differences, $F(2,6) = 1.705, p = .256$. This finding for controls would not be expected from Nairne's (1990) suggestion that interference plays a significant role in short-term memory, with degree of interference determined by the similarity of stimuli entering STM. Rather, it would be expected that in the written and spoken distractor condition an effect of interference would be seen, but not in the spatial task. It may be that the spatial task (i.e., object discrimination) is more difficult than the lexical decision tasks. However, given that only 4 subjects were tested, it is likely that some of these effects
were not significant simply due to lack of power.

It is something of a challenge to provide a plausible explanation for the results obtained for BS. Because in previous tasks BS has shown general decrease in performance with auditory materials as compared to visual materials, we expected his performance in the auditory condition to be impaired as compared to the visual condition across all distractor conditions. However the lack of differences in the degree of interference as a function of distractor type is somewhat puzzling. One explanation might be that he is relying on a semantic code in the auditory condition, rather than a phonological code. In this case, though his capacity is reduced, those representations that he does maintain would be not be subject to interference from the three types of distractor provided in this study. Presumably, if a semantic distractor condition had been included, we might expect to see interference in this condition. Considered in this light, the data suggest that because the controls' performance dropped between the written and spoken distractors, they are relying on phonology in the auditory condition. In contrast, BS shows no decrease in performance between the written and spoken conditions with auditory presentation, and in fact appears to be slightly better with the spoken distractor, which suggests that, in contrast to the controls, he is not relying on phonology in the auditory condition. If we assume that he is using semantics to do this task, then we might expect that there would be no difference in the auditory and visual conditions, as there is no reason to think that he gets any more semantic information from one or the other modalities. However, if he is relying on both semantic and visual (or
orthographic) information in the visual condition, then an advantage in this condition over the auditory condition would be expected.

**Table 6**

*Interference task: Mean number of words recalled per test list by list presentation condition and distractor type (control range in parentheses).*

<table>
<thead>
<tr>
<th></th>
<th>Spatial</th>
<th>Written</th>
<th>Spoken</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Auditory Presentation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BS</td>
<td>2.4</td>
<td>2.2</td>
<td>2.8</td>
</tr>
<tr>
<td>Controls</td>
<td>3.5 (2.4-4.8)</td>
<td>3.8 (3.4-4.6)</td>
<td>2.5 (1.8-3.2)</td>
</tr>
<tr>
<td><strong>Visual Presentation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BS</td>
<td>3.4</td>
<td>3.8</td>
<td>2.8</td>
</tr>
<tr>
<td>Controls</td>
<td>3.2 (2.4-3.8)</td>
<td>3.7 (3.4-4.2)</td>
<td>3.1 (2.0-5.0)</td>
</tr>
</tbody>
</table>

*Summary of short term memory tasks.* To review the findings in this series of tests, BS has demonstrated a general problem remembering auditory verbal stimuli, especially items that are phonologically confusing, or that have no semantic representation, such as non-words. He is fairly impaired in repetition. He does fairly well on tasks requiring the utilization of semantic material, such as the semantic probe tasks, and very
well with digits. However, though his span for digits is normal or above, his pattern of results on the visual digit recall was not normal. In the first set of 10 trials, he had no recency recall, and only in the third set (that is, after 20+ trials), did he show a recency effect for digits. He generally displays a robust negative recency effect for all stimulus materials, the exception being the free recall task, in which he did show a recency effect, but still quite reduced. He also displays a consistent advantage for visually presented materials. It appears that his deficit cannot be attributed to speech production alone, as he appeared to be impaired on the rhyme probe span task. His non-verbal memory is normal, as demonstrated by a visual span task, and a non-verbal sounds span task. His performance on the interference task reinforces the idea that he probably relies on the use of semantic codes, at least in the auditory condition, in short-term memory tasks.

In his reversed modality effect, lack of a recency effect and great difficulty with non-word materials, BS's performance is quite similar to those individuals who have been previously described in the literature as having an acquired phonological short-term memory deficit. However, unlike these individuals, he does show a phonological similarity effect in both auditory and visual modalities, though the effect is reduced with visual presentation. This is consistent with some developmental cases that have been described whose performance, as mentioned earlier, has been taken to suggest that they retain a limited ability to use phonological information, but choose not to when conditions make this kind of processing difficult or unreliable.
USES OF SHORT-TERM MEMORY

BS's performance on the above tasks has established that he does have a deficit in phonological short-term memory. The question arises as to the practical consequence of such a deficit. As mentioned above, there has been much recent interest in the function of phonological short-term memory. One hypothesis is that it is necessary for learning new phonological forms, such as vocabulary in both native and foreign languages, and much research has been done that supports this idea. There are some studies that link a phonological short-term memory deficit to other language processing abilities, including comprehension. In many fields that are heavily reliant on unique technical terminology, the need to acquire new information in conjunction with new phonological forms would be commonplace. For example, such words as *interon, exon,* (from molecular biology), *quark,* and *fullerene* (from structural physics), are words coined to describe structural phenomena within specific fields. On first exposure there is very little semantic content in these words to aid in recall and the cementing of phonology to the attendant meanings. It seems plausible that someone who has trouble holding on to phonological representations might therefore be handicapped in the acquisition of this type of knowledge. Similarly, learning of a foreign language would also be impaired.

Another commonplace activity for a student is the taking of notes in lectures, which is essentially writing to dictation. As suggested above, a deficit in phonological STM could plausibly have deleterious consequences for this type of activity, in that material could be lost as a consequence of
poor processing or retention before the student is able to write it down.

The fact that BS has earned his Ph.D. casts doubt upon the idea that
his deficit has impeded his education to any discernible degree. But, like
the developmental patient RE, BS's successes may be the result of elaborate
strategies developed over time to compensate for his deficit. For example,
it appears that he relies on visual input more heavily than people with
normal phonological memory. However, in situations where he must rely
on auditory input, his learning may be impaired. To assess the practical
consequences of his deficit, BS was given a number of different tasks in
different domains such as syntactic processing, reading, note taking,
learning utilizing familiar words, and the learning of new phonological
forms.

I. Syntactic processing.

Current evidence suggests that phonological short-term memory is
only involved in syntactic processing to the extent that storage of a
verbatim representation is necessary. However, there appears to be little
or no role for an articulatory component of phonological STM in sentence
comprehension (Martin, 1987,1993). Though BS's comprehension skills
appear to be intact, he has not been tested on tasks designed to assess
comprehension. BS was tested on comprehension of syntactically complex
sentence in order to provide further evidence on the dissociation between
phonological short-term memory and syntactic competence. In the
experiment below, he was given an sentence comprehension task in which
he had to detect whether a sentence was sensible or anomalous.
Experiment 10: *Sentence anomaly judgments.*

**Method**

**Materials and procedures.**

150 relative clause sentences were presented which ranged in difficulty of syntactic construction over 5 levels from easy to difficult (Martin, 1987). See Appendix A for examples. The sentences were recorded, digitized and presented auditorily on a computer. Half of the sentences were sensible and the other half were anomalous. An example of a sensible sentence is "*The football that was old was thrown by the quarterback.***", whereas an anomalous sentence was "*The quarterback that was old was thrown by the football***. BS listened to the sentences, and then made a judgment as to the acceptability of the sentence. His reaction times to the sentences were recorded, as well as his acceptability judgments.

**Results and Discussion**

BS made errors on 12% of the sentences, all but one of which were sensible sentences. Both the percentage errors and the pattern of response errors are within the range of the normal controls. The average normal error rate was 8.1%, the range was 6-14%. Most of these errors were made on sensible sentences. In addition, his reaction times were no longer than those of the normal controls. These data suggest that despite his deficit, his syntactic processing and comprehension abilities are not significantly compromised.

II. *Reading.*

A link between phonological STM and reading ability has been suggested by studies of the patient RE (Campbell & Butterworth, 1985;
Butterworth, Campbell & Howard, 1986). RE performed above average levels for standardized tests of reading, spelling and cognitive abilities. However, her reading of non-words, or unfamiliar words was very impaired. Though her auditory phoneme discrimination was normal, she was impaired at other auditory tasks, particularly those that required phonological awareness, such as rhyme judgments and segmenting auditorily presented words into their component sounds. Short term memory tests indicate that she has a severely reduced digit span, and that she does not use normal phonological coding in the performance of these tasks. In some respects, BS has a performance profile similar to RE. That is, difficulty with auditory tasks, especially those requiring phonological processing, such as rhyme tasks, poor recall for non-word stimuli, and failure to normally use phonological coding in recall tasks (as evidenced by negative recency effects in most tasks). RE was found to be significantly impaired on non-word reading, which was attributed to a specific inability to process phonological information. Though, like RE, BS has preserved abilities to make phoneme level discriminations, whether he can adequately map phonological units to their attendant sounds during reading was not known. To determine this, he was given a number of single non-word and syllable reading tests.

Experiment 11: Tests of non-word reading.

Method:

Materials and procedure:
BS was given 3 related reading tasks:

(1) 8 lists of non-words that were 10 items long, and comprised
simple or complex non-words ranging from of 2 phonemes to 4 phonemes long. In addition, he was asked to read lists of 4 items each composed of 2 syllable non-words of 5, 6, or 7 phonemes that were either simple, complex, or contained consonant clusters.

(2) A list of 25 non-word that corresponded to the body units of real words (e.g., orse, ust, atch, ull).

(3) A list of 23 consonant clusters.

(4) A list of 56 non-words that were divided into those that corresponded to the initial syllables of real words (e.g. cem, jeal, cres), and those that did not (e.g. mep, misp, nort).

He was told to read the lists at his own speed. His responses were recorded for later scoring.

**Results and discussion.**

BS performed this task almost flawlessly, making only 1 error on the 2 phoneme-complex non-word list ("as" for "azh"), and 2 errors on consonant clusters ("plu" for "pl", and "bla" for "bl"). And, although his reaction time was not analyzed, his reading was fluent and quite speedy. Thus, unlike RE, he seems to have no difficulty mapping the appropriate phonological codes to the graphemic information. In addition, he shows no difficulty in maintaining several representations of individual phonemes long enough to ensure proper blending of the phonemes in order to pronounce the non-words. His preserved ability to blend phonemes might be explained on the grounds that though his span for retaining phonological information is reduced, it is not zero. For example, on nonword repetition he could repeat some fairly lengthy nonwords correctly.
III Learning using familiar phonological forms.

It has been demonstrated that BS has some problems with repetition, even of familiar words, in span-like tasks. However, one might postulate that in order to acquire new knowledge, he must eventually be able to overcome such a handicap. Perhaps the repeated exposure to stimuli would allow for such learning to take place. In order to assess BS's ability to learn information based on known words, he was tested on a repeated list learning task.

Experiment 12: Repeated list learning.

Method.

Materials and Procedure. Lists of approximately the same syllable length were constructed of 96 different words. These words were equally drawn from four types of words: (1) high-frequency/ high imageability (HF-HI), (2) low-frequency/ high imageability (LF-HI), (3) high-frequency/ low imageability (HF-LI), and (4) low-frequency/ low imageability (LF-LI). The words of each type were arranged into lists of 6 words each. Thus, there were 4 lists of each of the 4 types of words. Each of these lists appeared only once in the experiment, so there were 16 trials of single presentation lists. In addition to these lists, there was one additional LF-LI list, which was repeated 8 times. Thus there were 24 trials in all. The order of the single presentation lists was random, but the repeated LF-LI list was interspersed among the other lists so that it occurred every third trial (i.e., as trial number 3, 6, 9, 12, 15, 18, 21, and 24). A trial consisted of the words of each list being read aloud to BS who then attempted to repeat them in the correct order.
Four adults matched for age and education served as control subjects for this test.

**Results and Discussion.**

Single presentation lists and the repeated LF-LI list were scored separately. Across all list and presentation types, BS was able to repeat only 1 of the 24 lists correctly, which was the repeated LF-LI list on the eighth repetition. In contrast, the control subjects repeated an average of 16.5 of 24 lists correctly (control range 12-20). As seen in Figure 8, in the single presentation lists, BS repeated an average of 4.5 words (of 6 possible) correct per list on HF-HI lists (control range = 4.75 - 6.00), 3.75 words per list on HF-LI lists (control range = 4.75 - 6.00), 4 words per list on LF-HI lists (control range = 4.75 - 5.75), and 2.75 words per list on LF-LI lists (control range = 3.75 - 5). On the repeated LF-LI list, averaging across all 8 presentations of the list, the number of words BS recalled per presentation was 4.25 (control range = 6-5.5). Thus he performed below the range for each of the different word types. None of the differences among these lists were significant for BS.
In the single presentation lists there is a strong negative recency effect for all list types indicating that BS receives little or no support from phonology. This is seen in Figure 9. As seen in Figure 10, in the repeated presentation LF-LI condition, there is also a negative recency effect which extends back to serial position 3. The controls performed close to ceiling on the repeated list, thus there were no serial position effects.
Figure 9
Repeated list learning: proportion words correct of the single presentation lists by list type and serial position (BS).
Finally, BS was unable to learn the repeated LF-LI list until the 8th presentation. In contrast, as seen in Figure 11, the control subjects learned it after an average of 2 repetitions (range 1-3). Thus, in this task BS is very impaired with regard to learning unfamiliar strings of known words.
IV. Foreign language learning

Experiment 13. Foreign language learning.

As mentioned above, one of the proposed uses of phonological STM is the acquisition of new phonological forms, such as new words and foreign languages. This has been born out by studies done on individuals with acquired deficits, and on those with developmental deficits. However, many of the individuals in the studies done previously have had a reduced digit span in addition to poor phonological short-term memory.
performance. BS is unusual in studies of this nature in that his digit span is normal or above. Nonetheless, according to current theory, if the learning of new phonological forms is dependent upon intact phonological short-term memory, BS should demonstrate a deficit in foreign language learning as compared to normals. Accordingly, we constructed a foreign language learning task similar to that used in previous studies (Baddeley, 1994) in which subjects are given two sets of word pairs to learn. In one set, the subjects are to learn random English word pairs. In the other set, they are given English words with their Serbo-Croatian translations.

**Method**

**Materials and procedure.** *English-English task.* A pool of 50 high imageability English words were selected and randomly paired to generate 25 paired associates. Of these, 8 pairs were randomly chosen to comprise the list to be learned by the subject. During the study phase, the subject was first auditory presented one word, then there was a 1 s pause, and then the associate word was presented. There was a 2 s pause between word pairs. When all 8 pairs had been presented a tone signaled the end of the study period. During the test phase, the subject was presented with the first word of a pair and was to name its associate. This continued until all 8 words had been tested. When the first trial was completed, the subject was again presented the list for study. The words pairs were randomized between trials so that the word pairs were always the same, but the order of presentation of the pairs was different for each study and test phase of each trial. The cycle of study and test continued until the subject correctly produced all 8 associates at test.
**English-Serbian task.** The stimuli were taken from a pool of 25 English words and their Serbian translations. The Serbian words were chosen in the following way: first, a large group of easily pronounced Serbian words, not exceeding three syllables in length, were selected from a Serbo-Croatian-English dictionary. Of these, only those words whose translations were familiar and concrete were selected. The resulting word pool comprised 25 English-Serbian word pairs. As with the English word pairs, 8 English-Serbian word pairs were randomly chosen as stimuli. The presentation conditions of the English-Serbian word pairs were identical to that of the English word pair task. As in the English word pairs, the study and test phases continued until the correct Serbian translations were produced for each word.

Controls for this experiment were 5 Rice graduate student volunteers.

**Result and discussion.**

On the English word pairs BS performed quite well, producing the correct associates to all the words after 3 trials. Though it is below the mean of the control subjects ($M = 2$ trials), it is within their range (range = 1-3 trials). As seen in Figure 12, on the English-Serbian task, he required 8 trials to reach criterion. Those normal subjects that performed around his level on the English-English task reached criterion on the English-Serbian task after 3-6 trials. All controls averaged together reached criterion at 6 trials. Thus, as compared to normal controls, BS appears somewhat impaired. In this task, as in others, he reported that in order to do the task, he had to create a visual image using the English words and
words that sounded similar to the corresponding Serbian word. (for example, *jump* = *skok* could be visualized as a person in a kilt, i.e., a Scot, jumping). This is reminiscent of the account of the developmental short-term memory subjects SR (Baddeley, 1994) and RE, in their attempts to learn new words.

One rather striking pattern evident in the analysis of his errors was the presence of perseverations in the words he produced. (see Appendix B). For example, in trial 2, he produced "selad" for three different words, none of which were correct. This would suggest that though the phonological code for the word "selad" was registered and maintained, perhaps with help of a semantic association such as "salad", he did not remember producing it earlier in the list. It may be speculated that though the Serbian word itself was maintained with the use of a semantic or lexical aid, there was no semantic association between the Serbian word and the English associate, therefore he had no anchor for his memory of producing the Serbian word.

The results of this experiment indicate that while a phonological short-term memory deficit is a handicap to learning new phonological forms, it does not entirely prevent this type of learning if the patient is capable of employing other means of remembering. Baddeley's developmental subject SR, though similar in some ways to BS, was not successful in performing a foreign language task, though the few successes he did have seem to have been accomplished in the same manner as reported by BS for his successes. The fact that BS has shown relatively preserved span with semantic materials supports the idea that he performs
these tasks using a combination of partially preserved phonological codes, supported heavily by semantic codes.

**Figure 12:**

*Foreign language learning task:* Words correct per trial: BS vs. the mean of controls in the English-Serbian task and the English-English task.
V Note taking.

Experiment 14. Dictation tasks.

This task was designed to determine the extent to which a phonological short-term deficit may cause problems in a situation that mimics a classroom lecture. In this task, a person must concurrently remember the current auditory phonological input while outputting the previous information in graphemic form. Subjects were required to take down to dictation several types of materials. These included digits, letters, words and sentences. Given BS's previous pattern of results, we expected that if he were given items that individually had no semantic meaning, such as letters, his performance would be depressed as compared to normal controls. However, if the material was semantically meaningful, he would be able to utilize the semantic representation to support recall and to use as an aid in constructing the output representation for writing. Given his facility with digits on previous tasks, we expected his performance to be unimpaired with digits.

Method

Subjects: Four adults matched for age were tested as control subjects for BS. Two of these controls were also matched for education, both in degree (Ph.D.) and content (molecular biology). The reasoning behind these particular controls was that those who engage in research in molecular biology (and like sciences) use numbers in every aspect of their work. Much of the "number work" is done mentally, without recourse to written material (it is too time consuming to take off protective gloves and clothing every time a calculation of molecular weight or molarity must be
made, therefore these sorts of calculations are routinely done in the head). This may have the affect of lending semantic association to certain sequences of numbers, as well as increasing the familiarity of these stimuli beyond that usually encountered in normal populations. For these reasons, controls with a similar background would be useful for ruling out such environmental explanations for BS's facility with numbers.

Materials and Procedure.

Digits: Randomized digits (1-9) were formed into 20 lists of 12 digits each. Ten of these lists were presented to the subjects at a rate of 1 item per s. The other ten lists were presented at a rate of 2 items per s (fast numbers).

Letters: The letters of the alphabet were randomized and the first 12 letters were formed into a list. This procedure was repeated until there were 20 lists of random letters. As with the digits, ten of these lists were presented to the subjects at a rate of 1 item per s. The other ten lists were presented at a rate of 2 items per s. (fast letters).

Words: Fifty common two syllable words were randomly selected from the Toronto Word Pool and formed into 5 lists of 10 words each. The same 50 words were randomized again, and again formed into 5 lists of 10 words each. One of these sets were presented at a rate of 1 item per second, and the other was presented at a rate of 2 items per second (fast words).

All the lists of items were recorded on tape, and played for the subject on a tape recorder.

Subjects were given paper and pencil and were instructed simply to
write down what they heard as if taking dictation.

Results and discussion:

The results are reported in Table 7. As expected BS performed as well as or better than the controls on taking dictation of numbers at a normal speed. However, in every other category, his performance is impaired relative to the average of the controls, and, in fact, is below the range of the control subjects. Such a result would be expected if his phonological processing, though accurate, is slow, or otherwise unreliable because the time constraints and the additional cognitive load of translation to an orthographic code, might prevent his efficiently employing semantic strategies as an aid. Another explanation might be a reduced capacity for phonological information. Because the writing of the information must necessarily lag behind the phonological input, and because writing will be slower than just comprehending, a larger amount of information must be stored until such time as it can be written down. This situation would be exacerbated with increasing speed of input as output rate is very likely to be the rate limiting step, which is consistent with the data. By t-test, the decrease in accurate recording of the dictation as a result of increasing speed is significant for BS (p = .004), but not for the controls (p = .31).
Table 8
Dictation task: Percentage correctly recorded items.

<table>
<thead>
<tr>
<th></th>
<th>BS</th>
<th>Control</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Letters</td>
<td>83.3</td>
<td>96.3</td>
<td>94.2-98.3</td>
</tr>
<tr>
<td>Numbers</td>
<td>100</td>
<td>99</td>
<td>96.7-100</td>
</tr>
<tr>
<td>Words</td>
<td>74</td>
<td>93.5</td>
<td>86-100</td>
</tr>
<tr>
<td>Fast letters</td>
<td>9.2</td>
<td>88.1</td>
<td>83.3-94.2</td>
</tr>
<tr>
<td>Fast numbers</td>
<td>88.3</td>
<td>95.0</td>
<td>93.3-96.7</td>
</tr>
<tr>
<td>Fast words</td>
<td>60.0</td>
<td>86.3</td>
<td>76-98</td>
</tr>
</tbody>
</table>

Thus one would expect that situations that call for this kind of dual processing would be a problem for BS. Fortunately, such circumstances are quite limited. Taking notes to lectures, an activity that BS surely has had to master, bears superficial resemblance to this task. However, in the type of courses that BS would encounter this situation would not likely exist in that the information he would be required to take notes on would be highly meaningful, which, from his performance on such tasks as the semantic probe task and the interference task, we would expect to provide adequate support for the immediate recall of such material. There is one circumstance, though, that does bear a close resemblance to this task. This is the writing down of names or phone numbers when taking a message over the phone. In this case, the input is purely auditory, and the person
taking the information would be required to write and listen concurrently. In this endeavor, we would expect BS to be significantly impaired. In fact, a survey of his co-workers revealed that it was assumed that if BS took a phone message, there was a "...less than a fifty-fifty chance..." of the information being correct, a fact that had caused bewilderment among his co-workers because of his usual meticulous attention to detail. Fortunately for BS, in molecular biology one's success is not often dependent upon one's ability to take down information over the phone.

GENERAL DISCUSSION

BS, the subject investigated in this study appears to have a developmental deficit of phonological short term memory. His deficit can be accounted for most economically by models of short-term memory that conceive of memory as a property of language processing components, rather than an separate entity. Although the working memory model of Baddeley has been widely used to explain phonological short term memory deficits, it has no way of accounting for the findings that suggest that BS's short-term memory is supported by semantic and lexical factors as well as phonological factors.

N. Martin and Saffran (1997) have suggested a model of memory in which there is a close relationship between language processing and short-term memory. This model is an interactive activation model in which auditory input activates phonological nodes within a phonological level of the network, which then spread activation to a lexical level, which in turn feeds upward to a semantic level. Activation can also spread backwards
from semantic to the lexical (and related) nodes and from the lexical level
down to the decaying phonological nodes (and related nodes). This model
is essentially a model designed for single word processing, and thus
suggests a very close link between the efficiency of single word processing
and short-term memory. However, this model is not able to account for
effects of connected text, or for order effects.

R. Martin and her colleagues suggest a model of short-term memory
in which, like the Martin & Saffran model, there is a close connection
between all levels of representations involved in language process and the
representations retained in STM. (Martin & Breedin, 1992; Martin,
Shelton, & Yaffee, 1994). However, this model conceives of verbal STM
as a limited capacity buffer where the phonological, lexical, semantic,
representations of a word are linked, as well as order information. The
representations stored in this buffer are the output of language processing,
but the quality of language processing and the capacity of the buffer, while
related, are not identical. Thus, in this model, single word processing may
be intact, while the capacity of the buffer may be damaged.

BS presents a pattern of performance which suggests that his
problems are within the buffer at the phonological level. His abilities to
process single words, as well as to read non-words suggest that his
phonological perception and segmentation abilities are intact. He is quite
able to map orthographic representations onto their corresponding sounds,
as is evidenced by his non-word reading. Further, it is unlikely that he is
using a strategy of accessing words that have similar phonology and
orthography in order to come up with the pronunciation, in so much as his
reading of non-words not corresponding to body units of real words was as
good as the non-words that did correspondence to the body units of real
words. BS's ability to read non-words easily may be explained by the fact
that though his span for auditory phonological information is reduced, it is
sufficient to meet the STM requirement for holding on to several phonemes
for the length of time necessary to blend them for reading purposes, unlike
some other developmental cases, such as RE. Within the model, the close
linkage between the phonological, lexical, and semantic levels of
representation allow for good performance for those verbal items that have
strong lexical and/or semantic representations, even if the phonological
representations do not persist. This is demonstrated by BS's preserved
performance on tasks that rely on semantic information, such as the
semantic probe task. However, representations that must be retained by
phonology alone, such as auditory non-words, are not retained well, or are
subject to more-than-average displacement. This is also true of tasks that
are driven by phonological information processing, such as the various
rhyme probe tasks. This suggests that BS has a reduced capacity at the
phonological level.

His performance with the dictation task can also be interpreted as the
result of a reduced capacity buffer. With all types of stimuli except digits
presented at a normal speed, his performance is below the range of the
normal controls. As discussed above, this could be the result of a reduced
capacity for holding information until it can be transferred into writing.
The controls did not show a significant decrement in performance as the
speed of dictation increased, thus increasing the amount of information that
had to be retained, but BS did. This is also suggestive of a capacity constraint. However, it is possible that very slow processing of phonological information might have a similar result.

The fact that BS experience no more interference from the spoken distractor than he did from the spatial or written distractors in the interference experiment, suggests once again that he relies on semantic codes. However, because a semantic distractor condition was not included in the experiment, no conclusion as to his susceptibility to interference can be made.

In contrast to other individuals with phonological short-term memory deficits, BS has demonstrated quite some resistance to the severe impairment in new language learning hypothesized to be the consequence of such a deficit. His ultimate learning in the language learning task, though slower than the controls, was very nearly normal. However, he does show impairment on a variety of other learning tasks, especially those in which his ability to utilize semantic information is limited, such as in learning lists of words of low frequency and imageability. This study present a coherent account of how someone with a fairly substantial deficit is able to succeed in academics by utilizing lexical and semantic information. It suggests that normal ability to process and retain phonological information is not necessarily crucial to learning. It also points out the few circumstances in which such a deficit cannot be overcome, namely in situations where only phonological information can be used, or under conditions where memory load is increased, and cannot be processed rapidly enough to compensate.
References


Appendix A

Examples of relative clause sentences used in the sentence anomaly judgment task, ranging in difficulty from easy (type 1) to difficult (type 5).

1. The quarterback that threw the football was old.
   The football that threw the quarterback was old.

2. The quarterback that was old threw the football.
   The football that was old threw the quarterback.

3. The football that was old was thrown by the quarterback.
   The quarterback that was old was thrown by the football.

4. The football that was thrown by the quarterback was old.
   The quarterback that was thrown by the football was old.

5. The football that the quarterback threw was old.
   The quarterback that the football threw was old.
Appendix B

Foreign language learning task: BS’s errors by trial and language condition.

English-Serbian

<table>
<thead>
<tr>
<th>TRIAL 1</th>
<th>Correct response</th>
<th>response produced</th>
</tr>
</thead>
<tbody>
<tr>
<td>div</td>
<td>NR</td>
<td></td>
</tr>
<tr>
<td>kvaka</td>
<td>NR</td>
<td></td>
</tr>
<tr>
<td>mlad</td>
<td>NR</td>
<td></td>
</tr>
<tr>
<td>stopala</td>
<td>MALOR</td>
<td></td>
</tr>
<tr>
<td>zag</td>
<td>SELAD</td>
<td></td>
</tr>
<tr>
<td>luk</td>
<td>ZUK</td>
<td></td>
</tr>
<tr>
<td>mokar</td>
<td>NR</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TRIAL 2</th>
<th>Correct response</th>
<th>response produced</th>
</tr>
</thead>
<tbody>
<tr>
<td>stopala</td>
<td>NR</td>
<td></td>
</tr>
<tr>
<td>div</td>
<td>selad</td>
<td></td>
</tr>
<tr>
<td>zag</td>
<td>malar</td>
<td></td>
</tr>
<tr>
<td>luk</td>
<td>selad</td>
<td></td>
</tr>
<tr>
<td>mlad</td>
<td>NR</td>
<td></td>
</tr>
<tr>
<td>kvaka</td>
<td>kvak</td>
<td></td>
</tr>
<tr>
<td>makar</td>
<td>makar</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TRIAL 3</th>
<th>Correct response</th>
<th>response produced</th>
</tr>
</thead>
<tbody>
<tr>
<td>stopala</td>
<td>mlad</td>
<td></td>
</tr>
<tr>
<td>luk</td>
<td>lots</td>
<td></td>
</tr>
<tr>
<td>div</td>
<td>mlad</td>
<td></td>
</tr>
<tr>
<td>mokar</td>
<td>NR</td>
<td></td>
</tr>
</tbody>
</table>
zag  zad
mlad  NR

Table 7, cont.

TRIAL 4
Correct response  response
produced
div  ziv
zag  ziv
mlad  NR

TRIAL 5
Correct response  response
produced
zag  zag
kvaka  kampala

TRIAL 6
Correct response  response
produced
kvaka  kompala

TRIAL 7
Correct response  response
produced
mokar  NR