RICE UNIVERSITY

Semantic and Phonological Representations
in Immediate Sentence Repetition

by

Nohsook Park

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APPROVED, THESIS COMMITTEE:

[Signature]
Randi C. Martin, Chair
Elma W. Schneider Professor of Psychology

[Signature]
David M. Lane, Associate Professor
Psychology

[Signature]
James R. Pomerantz, Professor
Psychology

Houston, Texas

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ABSTRACT

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Three experiments were conducted adopting the same paradigm used by Potter and Lombardi (1990) with two different types of lure words, ‘only semantically related’ and ‘both semantically and phonologically related’. Stimuli were presented either in rapid serial visual presentation or in auditory presentation. In Experiment 1, word lists preceded sentences whereas word lists followed sentences in Experiment 2. Greater SP than S intrusions were found in both experiments. Intrusions were higher in Experiment 2 than in Experiment 1 with only auditory presentation. These findings support the notion of phonological representations in short-term memory for sentences. With more closely controlled factors, the findings of Experiment 1 and 2 were replicated in Experiment 3. Experiment 3, furthermore, showed that encoding phonological information occurs at all position and is retained up to the point of recall.
Acknowledgments

This study was initiated two and half years ago. It has taken so long and there have been many people who have had a hand in its completion. As the process was long, the subsequent labor that was generated was extensive. Now at the point of completion, I am reminded of so many people who physically helped me complete the study and psychologically supported me through the process.

Randi Johnson and Michelle Boss helped make the study physically possible by aiding me in the creation of the stimuli and running most of the experiments. Special thanks should also go to Frank Tamborello who played a crucial role in completing the last experiment on time. I would further like to express deep appreciation to the committee, Dr. David Lane and Dr. James Pomerantz, for their strong encouragement and constructive comments that enhanced the quality of this study.

Despite the help of these and many unmentioned others, this paper would not be published without Dr. Randi Martin, my mentor. Throughout the entire study, she has been there guiding and nurturing me. I have to admit that towards the end, most of her efforts were probably directed at being patient with me. I can only spend a couple of lines to express how grateful I am to have had her as my mentor. This paper is undoubtedly the product of her tremendous effort to raise me as a researcher.

Lastly, I hold back tears as I write this page thinking of my parents and sisters who have been formidably supportive of me from thousands of miles away. Thank you all.
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INTRODUCTION

Sentence memory span, the number of words in a sentence that can be recalled, is much longer than the span of unrelated words. Span for unrelated words is typically five or six items whereas sentence span can range from 12 to 24 words. The longer span for sentence memory has been mainly attributed to the availability of semantic and syntactic representations in a sentence (Tejirian, 1968). Consequently, there have been many studies regarding the role of semantic and syntactic features in immediate memory of a sentence. On the other hand, phonological representations, which play a significant role in list memory, appear to play a lesser role and have been relatively neglected in sentence memory. Even a minimal role of phonology in sentence recall has been denied by Potter and Lombardi (1990) who proposed the Regeneration Hypothesis. This hypothesis states that sentence recall is performed by regenerating a sentence from the meaning of the original sentence using recently activated lexical items. The lexical items used in regeneration are not necessarily the words in the original sentence. To be selected, they just need to be highly activated and have the same meaning as the words in the original sentence. The gist of the hypothesis is that it is only semantic and conceptual information of the sentence plus lexical identity, without any ordered surface information, especially phonological, that contributes to sentence recall.

However, the results of the experiments that Potter and Lombardi (1990) have taken for their claims do not necessarily rule out phonological contribution to sentence recall. In addition, there are some lines of evidence suggesting that phonological codes do play a role in sentence memory. This evidence will be reviewed first, followed by a discussion of the evidence supporting the Regeneration Hypothesis and its evaluation.
Phonological Representations in Sentence Memory

There have been a number of reports suggesting a phonological representation in long-term memory of sentences using recognition tasks. Moeser (1974) ran a series of experiments in which subjects read sentences and later verified whether test sentences were the studied or changed ones. Sentence changes were made substituting one, two, or three words resulting in either a change in meaning or in wording. In the wording change condition, a mean of 2.25 synonyms were substituted in the original sentences, thereby changing wording but not meaning. Sentences in the meaning changing condition had a mean of 3 words substitutions which consequently changed the meaning of sentences. Subjects in both conditions were equally able to detect the changes of sentences that affected either wording or meaning as well as wording. If only the meaning of a sentence was stored in memory and used in the recognition task, then any changes in wording, not in meaning, should not have been recognized. Moeser also reported that subjects took a longer time to detect changes in meaning than wording. There would not have been any difference in the reaction times if only semantic information was needed in the recognition task.

Hayes-Roth and Hayes-Roth (1977) found an advantage with verbatim sentences over paraphrased sentences in a meaning verification task. Subjects read a series of sentences one at a time and were given a surprise recognition task in which they had to decide, with a confidence rating, whether or not test sentences had the same meaning as studied sentences. Test sentences were in two types - verbatim and paraphrased. Paraphrased sentences were different from the original sentences only in one verb that
was synonymous with the original verb. The mean of recognition rating was greater for verbatim than for paraphrased sentences. Subjects were also more confident in recognizing the verbatim than the paraphrased sentences. It is noteworthy that Hayes-Roth and Hayes-Roth specially instructed their subjects to concentrate on meaning not wording during the study stage. They also found reaction time was shorter for verbatim sentences than paraphrased sentences.

One may think that the results of these studies were shown because the similarity in meaning between the original and paraphrased sentences was not high enough. It does not seem to be the case, however. Moeser (1974) made an effort to control for the similarity in meaning by using sentence sets that three judges agreed to have highly similar meaning. Hayes-Roth and Hayes-Roth (1977) analyzed sentences that subjects rated high in meaning similarity. Hayes-Roth and Hayes-Roth also controlled for the familiarity effect by matching the number of presentation of words lest the better recognition of studied sentences be not due to its familiarity.

These two studies demonstrated that there is other than meaning information stored during the processing of sentences. There was no syntactical change in those sentence alterations. Thus, syntactic information is not the source for the wording detection nor the advantage with verbatim over paraphrased sentences. One possibility is that any surface-level storage that occurred before meaning-level integration survived to the long-term storage of memory. It is highly likely that the sustaining surface information is phonological which could be encoded during the viewing of sentences. Phonological encoding appears to be automatic process during reading (e.g., Colle & Welsh, 1976; Conrad, 1967; Levy, 1971). There was no effort in this experiment to
prevent phonological coding and enough time (seconds) was permitted to process each sentence completely.

Anderson (1971) examined directly whether there is a phonological representation in sentence memory. He instructed a group of subjects to read each sentence aloud repeatedly to make phonological encoding more likely. The other group of subjects was instructed to use a mental image of the event described in sentences to make semantic encoding more likely. Subjects' task was to fill in the blank for the subject noun in a sentence when the predicate was displayed along with the blank. Predicates were either verbatim or paraphrased. In paraphrased predicates, all the words were replaced with their synonyms with no syntactical change. Although the imagery group recalled better than the repetition group, overall, the recall given a verbatim cue was significantly better than given a paraphrase cue. The author attributed the advantage with a verbatim cue to the contribution of phonological representations. The probability of a correct response to a paraphrased cue given a correct response to the verbatim cue based on the same sentence was .922 in the imagery group and .827 in the repetition group. This means that the phonological encoding of the repetition group was stronger than that of the imagery group.

Based on these data, Anderson (1971) reached the conclusion as follows:

These data appear to make untenable the position that phonological and semantic encoding give rise to forms of long-term storage which can be used alternatively, depending upon S's strategy or circumstances ···· the conclusion seems to be that while the long-term storage of sentences usually entails semantic encoding,
surface orthographic or phonological information is encoded at least some of the
time and can be sufficient for recall from the long-term store. (p. 340)

The studies have been illustrated so far indicate that there is a phonological
representation in the long-term memory of sentence, with the range of 10 seconds to 10
minutes time parameters, carried over from the short-term store of sentence memory.
Sachs (1974) investigated the duration of surface level and meaning level information at
different points in time. Subjects’ performance in the lexical and the identical conditions
among others are relevant to the current topic. In the lexical condition, one synonymous
word was substituted for the original word in a sentence such as “ship” for “boat” (from
Sachs, 1974). In both study and test phases, auditory and visual modalities were
employed. Different voices were used in the auditory version and different displays of
the text in the visual. Thus, acoustic and iconic cues were absent in the identical
condition. The time parameter was constructed as the number of intervening syllables, 0,
20, 40, and 80 (equivalent to 3 s, 7.5 s, 12.5 s, & 23 s with auditory presentation; 1 s, 4 s,
8.5 s, & 16.5 s with visual presentation). In the analysis, the performance with the
identical sentences was used as control. Subjects were able to detect the changes in
wording (lexical condition) at 0-syllable delay way beyond the chance level both with
auditory and visual presentation (the percentage of deviation from “chance” performance
was about 67% and 33%, respectively). Memory for the precise wording of sentences
dropped to the below the chance level between the 0-syllable and 20-syllable delay.
Considering the testing sentences were in a connected discourse, semantic encoding more
likely occurred than phonological encoding. So the duration and the strength of
phonological representation could be longer and stronger in isolated sentences. Another
important finding of this study is that phonological code is stronger with auditory presentation than with visual presentation albeit the similar patterns of the time course. It appears that phonological information is processed in the early stage (based on the quicker reaction time to detect wording than meaning changes) and fades quickly.

Another piece of evidence that suggests a phonological representation in immediate memory of sentence is from the suffix effect in sentences. The suffix effect is one prominent characteristic of list memory. When an auditory list of unrelated words is followed by an additional redundant sound called the suffix, there is considerable interference with memory for the last few list items (e.g., Morton, Crowder, & Prussin, 1971). Using the task of transcribing definitions from auditory stimuli, Balota, Cowan, and Engle (1990) showed that the suffix effect also appeared in immediate memory of a sentence. They proposed that the suffix interferes with a surface-level representation of the last few list items because meaning-level integration across the words has not yet occurred before the suffix is presented. Longer sentences (20 words) produced a larger suffix effect than short ones (15 words). The effect was larger when subjects wrote down as they heard the definition (immediate condition) than when subjects started writing after they finished hearing the sentence and suffix sound (delay condition).

According to Balota, Cowan, and Engle (1990), the degree of the suffix effect is related to the reliance on the surface representation. As sentence length increases, memory load becomes greater and consequently greater reliance may be drawn upon information at the surface-level. The authors attributed the suffix effect in the study to a phonological representation. They speculated that phonological information could be useful in retrieving the sentence when the processing system becomes overloaded and the
semantic process lags behind the incoming information. It provides a good explanation for the larger suffix effect in the immediate condition than in the delayed condition. In the immediate condition, subjects may not have had enough time to comprehend the sentence fully while they were writing and become more reliant on the memory of the phonological information. In the delayed condition, the subjects should have had sufficient time to process the information up to meaning integration before writing began. Thus, there may have been less reliance on phonological representations in the delayed-recall procedure resulting in a small suffix effect. This idea is consistent with the fact that the effect was eliminated when the subjects were presented with linguistically coherent stories and instructed to focus on the overall meaning of sentences (Balota et al.).

As illustrated so far, from the early literature, it has been shown that there is a phonological representation involved in immediate sentence memory although experiments were not precisely designed to tease apart a phonological representation from others. Potter and Lombardi (1990), however, found evidence that they interpreted as arguing against maintenance of an ordered surface representation, especially phonological. Their findings and theoretical claims are outlined below.

Regeneration Hypothesis

Potter and Lombardi (1990) proposed the Regeneration Hypothesis by which they rejected the involvement of a phonological representation in verbatim sentence recall. According to their hypothesis, only a conceptual representation of a sentence is retained. Sentence recall is accomplished by employing normal speech production mechanisms
(see, for example, Bock, 1982, 1986; Garrett, 1982; Levelt, 1989) based on the stored message of a sentence, which resembles the long-term memory of a sentence. The whole meaning of a sentence is stored in a propositional form in which the relations among words in the sentence are expressed. When the sentence is to be recalled verbatim, lexical items that are the most active will be employed. There is no surface form of the sentence remaining since the meaning of the sentence is stored in a propositional form. Lexical representations of all of the content words are activated in no specific order and do not contain phonological information.

According to Potter and Lomardi’s (1990) hypothesis, the reason why we see verbatim recall of a sentence is that the lexical items in the sentence are more likely to be active than any other lexical items that could be used to construct the meaning of to-be-recalled sentence. However, if there is another lexical item that has the same meaning as the one in the original sentence, and that item is more active than the original one, it will be selected during the reconstruction of the sentence. Evidence for these claims came from the results of a study using dual-task paradigm of word-recognition and sentence recall. A memory list of five words was presented in RSVP fashion and a sentence followed or preceded the memory list in the same rapid presentation mode. Subjects were presented with a probe word and had to decide whether it was in the memory list. They were then instructed to recall the sentence. Among the five words in the word list, there was a lure word semantically related to a target word in the sentence. The lure words had been chosen to be more frequent and to fit more naturally in the sentence than the target words. Subjects tended frequently and unconsciously to recall the sentence
with the lure word rather than the target word. The RSVP mode was implemented since normal people would hardly make mistakes in sentence recall with natural reading speed.

Potter and Lombardi (1990) argued that these results demonstrated that there were conceptual and lexical processes involved in immediate sentence memory, as they had hypothesized. They maintained that during sentence recall, a new sentence is generated starting from the remembered meaning of the studied sentence, incorporating the active lexical items that are consistent with this meaning. Since the lure word has the same meaning as the target word, if somehow the lure word has higher activation than the target word, the lure word will be selected with the other words which, altogether, make up a sentence with the intended meaning. What makes the hypothesis questionable is the strong claim that no ordered surface representation of the sequence of words is involved in sentence recall despite the fact the ordered auditory information is important in list recall. The rationale for this claim is that if there was any phonological contribution, the lure words that were not phonologically similar to the target words would not have been selected during sentence regeneration. In essence, Potter and Lombardi have rejected the division of memory for sentences between short-term verbatim memory and long-term memory based on gist. Even in immediate recall, the process is the same as in long-term memory, according to their argument.

Evaluation of the Regeneration Hypothesis

Potter and Lombardi’s (1990) study clearly shows a semantic contribution to sentence recall. Their claim, however, that there is no phonological information involved in short-term memory of sentence does not seem justifiable only based on their study.
Their results show that phonology does not play a strong role enough to prevent intrusion of semantically related words, not that there is no phonological contribution to verbatim sentence recall. Katz (1998) made this argument against the Regeneration Hypothesis and carried out further investigation. He conjectured that the reason why Potter and Lombardi (1990) could see pure semantic substitutions was because of a weak phonological code for the words. He tested this conjecture using the same RSVP paradigm as Potter and Lombardi’s, with two types of lures, semantically related and phonologically plus semantically related, for the same target word in a sentence. He implicated a phonological contribution by demonstrating a higher rate of intrusions with phonologically and semantically related lures than with only semantically related lures. He also demonstrated pure phonological intrusions with lures that were highly phonologically similar to the targets (though differing in meaning).

Rummer and Engelkamp (2001) also tested the involvement of a phonological code in sentence repetition with the same material, translated into German, and the same paradigm as used in Potter and Lombardi's study. They looked at the relationship between modality and sequential order in sentence recall. They found that, under RSVP, recall was unaffected by whether sentences were presented before or after the list. There was a sequential order effect with auditory presentation, however. Recall was better when the sentences followed the list than when the sentences preceded the list. For an explanation of the absence of the sequential order effect under RSVP, they maintained that RSVP does not allow enough time for the visual code to be transformed into a phonological form, if any, decays rapidly. Hence, even if the sentence were presented just before recall, it would not provide an advantage for recent items because the
phonological information is not available under RSVP. Therefore, under RSVP, sentence recall needs to be dependent on mainly conceptual information. With auditory presentation, on the other hand, the acoustic information is automatically encoded into phonological form and the phonological information is still available when the sentence is presented after the list. Phonological information is not available, however, when the sentence precedes the list, due to decay and/or phonological interference with the list.

Rummer and Engelkamp (2001) further reasoned that there would be fewer intrusions if the target words in sentences were located close to the end of the sentences when the list preceded the sentences, due to the salient phonological information of those target words. Since phonological codes are available only with auditorily presented stimuli, according to their assumptions, reduced intrusions should be found only under auditory modality not with RSVP. They modified the sentences so that the targets occurred at the latest location in the sentences. Intrusions under auditory presentation when the list preceded the sentences were reduced as they predicted while there was no dramatic changes in other conditions. The results are consistent with the logic of Rummer and Engelkamp (2001) that phonological information is encoded only under auditory presentation and in list-sentence order. According to Katz's study (1998), however, a phonological representation is encoded in memory even with visual presentation as reviewed earlier.

Neuropsychological Evidence for a Phonological Contribution to Sentence Memory

The grounds for the hypothesis that there is a phonological component in sentence recall, in parallel with a semantic component, include evidence from studies of brain
damaged patients. Patient EA was reported to show a consistent pattern of a deficit in phonological retention in short-term whereas patient AB showed the reverse yet consistent pattern related to deficit in semantic retention in short-term memory (Martin, Shelton, & Yaffee, 1994). In detail, AB displayed normal effects related to phonological variables such as better recall with auditory presentation than with visual presentation, a recency effect, and word-length effects. EA, on the other hand, did not show any of these effects. AB was better than EA at recalling letter lists while EA was slightly better than AB on the concrete word task. Normal people have shown to have advantage with words in recall over nonwords. EA also displayed the advantage, more than normal, whereas AB did not show a benefit for words. Therefore, it is apparent that the two patients relied on different components of short-term memory, semantic and phonological, albeit both had a similarly reduced short-term span.

If only semantic representations are called upon in sentence repetition, as Potter and Lombardi (1990) claimed, one would expect that EA’s sentence repetition should be normal given her intact semantic capacity or at least better than AB. On the other hand, AB should be poor at sentence repetition given his lack of benefiting from semantic information. It turned out to be not the case, however. Martin, Shelton, and Yaffee (1994) reported that EA could not repeat any sentences with simple syntax while AB recalled 68% of sentences with 8 words and 8% of sentences with 10 words. Their error types also indicate that the patients carried over the patterns of their short-term memory for lists to sentence repetition. EA often paraphrased sentences (15 of 29 incorrectly repeated sentences) whereas only 1 sentence was paraphrased in AB’s incorrectly repeated sentences. Data from patients EA and AB are directly against what Potter and
Lombardi (1990) who rejected the similarity between short-term list memory and immediate memory of sentences, specifically, phonological characteristics. More importantly, the data from these patients provide the evidence that phonological processing is required in sentence repetition.

Another double dissociation between phonological and semantic short-term memory and sentence recall is from the study with two closed head-injured children. Hanten and Martin (2000) systematically examined CS and CB who provided an analogy to the case of EA and AB. Like EA, CS showed a dominant reliance on semantic code on retention tasks presumably due to her difficulty in retaining phonological information. She showed poor nonword list recall, no recency effect, a big advantage with words over nonwords and a large advantage with high imageability words. CB’s phonological retention was also impaired, but his phonological capacity was less impaired than CS’. His semantic capacity was shown to be more impaired than his phonological retention. In sentence repetition, CB was better than CS. These two cases strongly suggest that a phonological representation plays an important role for immediate memory of sentences.

CURRENT STUDY

Based on the compelling evidence for a phonological representation in verbatim sentence recall, three experiments were conducted to provide a more comprehensive evaluation of the processes involved in immediate sentence repetition. Experiments 1 and 2 were carried out to replicate Katz’s (1998) finding using materials intended to induce a larger proportion of intrusion, more in line with those found by Potter and Lombardi. Experiment 3 was designed in such a way to enable exploration of the time
course of semantic and, especially, phonological codes by looking at the effect of target position. It also controlled for potential confounds in Experiments 1 and 2 such as target positions, sentence length, and presentation rate.

Experiments 1 and 2 were designed and conducted by modifying Experiment 4 in Katz's (1998) study. The shortcoming of Katz's study was that the intrusion rates were exceedingly low especially for semantically related lure words (2% for induced and 1% for spontaneous), much lower than that obtained by Potter and Lombardi (1990). In Katz's study, each sentence was paired with three different types of lures – semantically related, phonologically and semantically related, and only phonologically related lures. It is not hard to imagine the difficulty in matching the lure types on various factors such as length, imageability, frequency and fit to the sentence. These constraints deprived Katz of freedom in choosing the stimuli and may have caused the low intrusion rate, for instance by limiting the lures to a set which were not highly probable words in the sentences. In the present study, separate sets of sentences and lures were created for each lure type, while controlling for other possible factors that may contribute to the difference on intrusion rate.

Additionally, two more independent variables were included that were not in Katz's study – modality of presentation (visual vs. auditory) and sequential order of sentence and memory list presentation (MS vs. SM). According to literature, the amount of encoded semantic and phonological information is different with different modalities and the memory trace of the semantic and phonological codes also vary over time. For instance, list recall is better with auditory presentation than visual and the last few items are more memorable than items that are presented in the middle of a list. These
advantages with auditory modality and in last positions are attributed to richer acoustic and phonological information. As reviewed earlier in this paper, these phenomena were found in sentence memory as well. Auditory modality gives rise to richer phonological representations (Rummer & Engelkamp, 2001). The last items in a sentence seem to bear more phonological information than in the middle and are consequently susceptible to a suffix effect (Balota, Cowan, & Engle, 1990). Based on the findings, the variables of modality and sequential order were included to provide more information about the nature of the immediate memory for sentences regarding timing.

A preliminary study was conducted to collect norms to control for possible factors that may create any difference in intrusion rates other than phonological and semantic relatedness between a target and the lure. Those factors were frequency, word length, concreteness, semantic similarity between a target and the lure word, and naturalness of the sentences. The frequencies of the words were found in Francis and Kucera’s (1982) database. Concreteness, semantic similarity, and naturalness of sentences were estimated by 82 Rice undergraduates. Semantic similarity refers to how similar the target and lure words were in terms of the meaning in the sentence. Naturalness refers to how natural the sentence sounds. Cloze rate was used as the index of naturalness. Subjects were given sentences with a blank for the crucial word and asked to fill in the blank with a word which makes the sentence sound natural. The cloze rates of each sentence with target and lure were calculated separately as a percentage of the occurrence of the word out of the total number of trials.

Finally, a total of 80 sentences, 40 for the SP condition and 40 for the S condition, were selected with each having a set of target and lure word. Table 1 shows that there
was virtually no difference between the SP and S conditions in terms of frequency, word length, sentence length, concreteness, semantic similarity between target and lure, and cloze rate. The lure words were selected to have higher cloze rates than the target words so that a meaningful intrusion rate would occur. These are the possible factors that might contribute to inducing a difference in intrusion rates. Accordingly, the only source of difference that we may see in intrusion rates between SP and S conditions is presumably the phonological and semantic relatedness between target and lure.

Table 1

**Controlled Factors for Experiments 1 & 2**

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EXPERIMENT 1

Method

Participants
Sixty-four undergraduate students at Rice University who were taking introductory Psychology classes participated in this experiment in order to fulfill their experiment participation requirement for their Psychology classes. All of them were native English speakers.

Materials
Eighty sentences, 40 in the SP condition and 40 in the S condition, were constructed. Each sentence had a set of noun lure word and a memory list of five words. Each word list included a lure word that was semantically and phonologically related, in the SP condition, and only semantically related, in the S condition, to the target word in the sentence. Four other words in the list were nouns similar to the target in length, but semantically and phonologically unrelated to the target. A probe word was selected half the time from the list, in different positions, and the other half of the time from outside the list. The lure word was never presented as the last item in the list nor as the probe word.

Design and Procedure
The experiment was designed using the Psycscope experiment-construction program (Cohen & MacWhinney, 1994) and implemented on a Macintosh Performa 6400 using a similar paradigm as Potter and Lombardi used (1990). Each subject processed 80 sentences in total, 40 with auditory presentation and 40 with visual presentation. Half of the subjects were given the auditory version first and the other half was presented with
the visual version first. In the visual condition, the sentence and the list were presented in
the form of RSVP (rapid serial visual presentation). All of the stimuli was displayed in
the center of the computer screen under RSVP. The sound was projected from the
speakers of the computer in the auditory presentation condition.

Figures 1a and 1b show brief depictions of the experimental paradigm for visual
presentation and auditory. The experiment began by hitting the spacebar. A row of
asterisks was displayed for 300 ms followed by a 350 ms blank. Then the list of five
words was presented, with a duration of 250 ms for each word. After another row of
asterisks for 250 ms, a sentence was presented at the rate of 200 ms per word. The first
word of the sentence was capitalized but there was no punctuation after the last word of
the sentence. Each word in the list and in the sentence was displayed one at a time.
Finally, a probe word in capitals was presented for 500 ms following a row of percentage
signs as a visual mask. Then a subject was instructed to decide whether the probe was in
the list or not and press the ‘YES’ or the ‘NO’ key depending on the answer. Half of
time, the accurate response was ‘YES’ and ‘NO’ for the other half. Immediately after the
word recognition task, subjects recalled the sentence aloud, speaking into a microphone
as accurately as possible. The responses in sentence recall were recorded by the
experimenter and scored later. Lure words were presented equally in the first four
position of lists, but never at the end of the list nor as a probe. A set of memory lists and
sentences was randomly presented, and each subject was given a different order of the set
of lists and sentences. For half the experimental trials, the list contained the lure.

Subjects were provided with five practice trials before the experimental trials. For most
Figure 1

a. Experimental Paradigm for Visual Presentation

LW: list word
One word at a time
Presentation rate 250 ms

SW: sentence word
One word at a time
Presentation rate 200 ms

P: probe word
Word recognition

Sentence Repetition

b. Experimental Paradigm for Auditory Presentation

LW: list word
Presentation rate 350 ms

S: sentence
Sentence duration was matched to that of visual version

P: probe word
Word recognition

Sentence Repetition

subjects, five practice trials were more than enough for them to get accustomed to the fast presentation rate.

In the auditory version, sentence duration was matched to that of visual version as closely as possible using the SoundEdit program. Sentences were recorded with natural
prosody and intonation. The whole presentation rate of a sentence was matched to that of visual presentation. It was not possible to recognize auditory list words at 250 ms per word, so they were presented at rate of 350 ms. Probe words were presented as normal speech. Sentences and words were recorded by a female American English speaker.

Subjects were told that this study was designed to examine how people managed to do dual tasks, word recognition and sentence recall. After the experiment they were given the debriefing for the actual study and asked not to tell any other possible subjects about the nature of this study.

Results

Accuracy of word recognition and sentence recall is presented in Table 2. Only the data from subjects whose recognition accuracy was higher than 60% were included in the analysis. All the subjects received accuracy higher than 60% of the trials resulting in the average of 80% accuracy with auditory and 77% with visual presentation.

Table 2

<table>
<thead>
<tr>
<th>Presentation Modality</th>
<th>Task</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Word Recognition</td>
</tr>
<tr>
<td>Auditory</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>Sentence Recall</td>
</tr>
<tr>
<td>Visual</td>
<td>77</td>
</tr>
<tr>
<td></td>
<td>83</td>
</tr>
</tbody>
</table>
Table 3

Percentage of Intrusions of SP and S from Experiment 1 (Memory list – Sentence Order)

<table>
<thead>
<tr>
<th>Presentation Modality</th>
<th>Stimulus Type</th>
<th>SP WithLure</th>
<th>SP WithoutLure</th>
<th>S WithLure</th>
<th>S WithoutLure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auditory</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With-Without</td>
<td></td>
<td>20</td>
<td>12</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td></td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Visual</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With-Without</td>
<td></td>
<td>21</td>
<td>9</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12</td>
<td></td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

Sentence recall was scored by counting the correctly produced words other than the target word in a sentence. A word was scored correct when it was produced in the exact form and position in the sentence as the original. Sentence recall for other than the target word was highly accurate despite the rapid presentation rate (86% with auditory presentation and 83% with visual presentation).

The intrusion-rate variable is of the main interest in this study (see Table 3). The subjects’ responses were scored in terms of the percentage of intrusions of the lure word for the target when the lure was presented in the list or not presented (i.e., a spontaneous intrusion of the lure word). With auditory presentation, there was a higher intrusion rate in the SP condition than in the S condition, 20% and 6% of the trials, respectively. The higher intrusion rate for the SP condition compared to the S condition also was revealed with visual presentation, 21% and 8% of the trials, respectively. Subjects also made
intrusions where there was no lure words embedded in the lists. The spontaneous intrusion also showed the same pattern as the induced intrusions with both modalities. With auditory presentation, spontaneous intrusions in the SP condition were again higher than in the S condition, 12% and 3% with visual presentation, 9% and 3% with auditory presentation.

The focus of this study is the intrusion rate, so a statistical report of only this variable will be presented in this paper. A three-way repeated measures ANOVA was conducted including lure type (S vs. SP), modality (visual vs. auditory), and presence of lure (induced vs. spontaneous) as factors. $F_1$ and $F_2$ denote the statistics obtained from the analysis by subject and by item, respectively, as a random factor. These denotations will be used throughout the paper. Of most importance, there was a significant difference in intrusion rates with two types of lure words, by taking subjects as a random factor $F_1(1, 63) = 155.40, \text{MSE} = 90.94, p < 0.001$, or items as a random factor $F_2(1, 78) = 12.56, \text{MSE} = 687.94, p = 0.001$. The effect of presence of a lure was significant, $F_1 (1, 63) = 57.53, \text{MSE} = 139.90, p < 0.001, F_2 (1, 78) = 57.455, \text{MSE} = 82.08, p < 0.0001$. Also there was a significant interaction found between lure type and presence of lure, $F_1 (1, 63) = 8.19, \text{MSE} = 120.29, p = 0.01, F_2 (1, 78) = 9.52, \text{MSE} = 82.08, p < 0.001$. The difference between the intrusions with SP words and the intrusion with S words was greater in the lure present condition than in the absent. No other effects were significant.

**Discussion**

The results from Experiment 1 contradicted Potter and Lombardi’s (1990) claim that no phonological information of a sentence is stored in memory. A higher intrusion
rate with SP than with S words was prominent. Such prominence was found not only when lures were embedded in the lists also without lures in the list. Note that there are no other known sources for the differences than the phonological relatedness of the target and the lure. Thus, the fact that spontaneous intrusions were higher with SP than S words, while controlling for other possible factors, also provides evidence that subjects recall sentences using a phonological code. It is speculated that incoming words spread their activation to other words connected to the target. It is possible that both semantically and phonologically related words would get activated more than only semantically related words leading to a higher spontaneous intrusion rate even when there are no lure words presented. The interaction between lure type and presence of lure rules out any possibility that the greater intrusions with SP than S words are due to any other uncontrolled factors, however.

These findings all together provide evidence, consistent with Katz’s (1998) study, that a phonological representation is durable and gets utilized in immediate sentence recall. Phonological information was revealed to be used under both RSVP and auditory conditions, unlike what Rummer and Engelkamp (2001) stated, given that intrusions were greater with SP than with S words in both modalities. In this experiment where the sentences were preceded by the memory list, the two different modalities did not produce any difference in intrusion rate. Rummer and Engelkamp’s findings suggest that differences between the two modalities may be observed when the list follows the sentence. This is investigated in the next Experiment.
EXPERIMENT 2

Method

Participants

Fifty-two Rice undergraduates who were not in Experiment 1 participated for credit required for psychology classes. All of them were native English speakers.

Materials

The same materials as in Experiment 1 were used.

Design and Procedure

Sentences preceded lists. Everything else was the same as in Experiment 1.

Results

The accuracy of word recognition and sentence recall is presented in Table 4. The mean percentage for accurate word recognition was 92% with auditory presentation and 80% with visual presentation. The high accuracy of word recognition with auditory presentation is noteworthy. Sentence recall other than target words was 81% with auditory presentation and 85% with visual presentation.

Table 4

<table>
<thead>
<tr>
<th>Presentation Modality</th>
<th>Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auditory</td>
<td>Word Recognition</td>
</tr>
<tr>
<td></td>
<td>92</td>
</tr>
<tr>
<td>Visual</td>
<td>80</td>
</tr>
</tbody>
</table>
Intrusion rates are depicted in Table 5. All the intrusion rates were higher than those in Experiment 1. As in Experiment 1, more intrusions were made with SP words than with S words with both presentation modalities. In detail, intrusion rates with auditory presentation were 40% with SP words and 27% with S words. Fewer intrusions were made with visual presentation, 19% with SP words and 10% with S words. There were again spontaneous intrusions, but the occurrences were still much more frequent with lures as seen in Table 5. Greater intrusions with SP than S words were shown both in induced and spontaneous conditions. Interestingly enough, spontaneous intrusions were made more with SM order. Intrusion rates were higher for the auditory than the

Table 5

<table>
<thead>
<tr>
<th>Presentation Modality</th>
<th>Stimulus Type</th>
<th>WithLure</th>
<th>WithoutLure</th>
<th>WithLure</th>
<th>WithoutLure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SP</td>
<td></td>
<td></td>
<td>S</td>
<td></td>
</tr>
<tr>
<td>Audiory</td>
<td>With-WITH</td>
<td>40</td>
<td>19</td>
<td>27</td>
<td>8</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>With-Without</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>21</td>
<td>19</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>Visual</td>
<td>With-WITH</td>
<td>19</td>
<td>14</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>With-Without</td>
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<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>14</td>
<td>10</td>
<td>5</td>
</tr>
</tbody>
</table>

visual condition overall, and the presence of a lure appeared to have a greater influence on intrusion in the auditory condition.

To assess these patterns statistically, a repeated measures ANOVA was carried out with three factors, lure type (SP vs. S), modality (visual vs. auditory), and presence of
lure (induced vs. spontaneous). The analysis revealed that all three main effects were significant: modality, $F_1 (1, 51) = 69.66$, $MSE = 193.83$, $p < 0.001$, $F_2 (1, 78) = 88.90$, $MSE = 102.77$, $p < 0.001$; lure type, $F_1 (1, 51) = 101.35$, $MSE = 105.60$, $p < 0.001$, $F_2 (1, 78) = 8.82$, $MSE = 917.10$, $p < 0.01$; and presence of lure, $F_1 (1.51) = 74.90$, $MSE = 211.97$, $p < 0.001$, $F_2 (1, 78) = 90.39$, $MSE = 133.47$, $p < 0.001$. The only significant interaction was the two-way interaction between modality and presence of lure, $F_1 (1, 51) = 33.60$, $MSE = 158.84$, $p < 0.001$, $F_2 (1, 78) = 56.24$, $MSE = 73.41$, $p < 0.001$, with the presence of a lure having a greater effect in the auditory modality. Unlike in Experiment 1, the interaction between lure type and presence of lure failed to reach significance. Thus, some of the patterns appeared different across the two experiments. In order to test whether these differences were significant, another repeated measures ANOVA was conducted with the data from both experiments.

The data from two experiments were combined for further analysis regarding sequential order. There were four factors in this analysis - lure type (SP vs. S), modality (visual vs. auditory), presence of lure (induced vs. spontaneous), and sequential order, that is, experiment (MS vs. SM). Significant main effects were found for all of the four factors: lure type, $F_1 (1, 114) = 23.86$, $MSE = 0.009$, $p < 0.001$, $F_2 (1, 78) = 11.155$, $MSE = 0.15$, $p = 0.001$; modality, $F_1 (1, 114) = 33.31$, $MSE = 0.02$, $p < 0.001$, $F_2 (1, 78) = 46.30$, $MSE = 0.01$, $p < 0.001$; presence of lure, $F_1 (1, 114) = 131.90$, $MSE = 0.02$, $p < 0.001$, $F_2 (1, 78) = 122.47$, $MSE = 0.01$, $p < 0.001$; and sequential order, $F_1 (1, 114) = 51.19$, $MSE = 0.03$, $p < 0.001$, $F_2 (1, 78) = 67.99$, $MSE = 0.01$, $p < 0.001$. Four two-way interactions were significant: luretype and presence of lure, $F_1 (1, 114) = 6.194$, $MSE = 0.09$, $p = 0.014$; $F_2 (1, 78) = 3.98$, $MSE = 0.01$, $p = 0.05$; modality and sequential order...
F₁ (1, 114) = 30.86, MSE = 0.02, p < 0.001; F₂ (1, 78) = 66.57, MSE = 0.07, p < 0.001; modality and presence of lure, F₁ (1, 114) = 20.12, MSE = 0.01, p < 0.001, F₂ (1, 78) = 17.93, MSE = 0.008, p < 0.001; and presence of lure and sequential order, F₁ (1, 114) = 5.75, MSE = 0.02, p < 0.018; F₂ (1, 78) = 11.08, MSE = 0.01, p = 0.001. The interaction between lure type and modality was significant only by subjects, F₁ (1, 114) = 5.860, MSE = 0.01, p = 0.017, F₂ (1, 78) = 1.69, MSE = 0.01, p = 0.197. The three-way interaction of modality, presence of lure, and sequential order was also significant F₁ (1, 114) = 45.39, MSE = 0.01, p < 0.001; F₂ (1, 78) = 71.18, MSE = 0.004, p < 0.001. The three-way interaction reflected the fact that in Experiment 1, the increase in intrusions with lure present compared to lure absent was slightly less in the auditory (5%) than the visual modality (9%) whereas in Experiment 2, a much greater number of intrusions with lure present compared to lure absent was observed for the auditory condition (20%) relative to the visual condition (5%).

Discussion

Sentence recall was reduced compared to that of MS order with auditory presentation (86% in MS order; 81% in SM order). Such a reduction was not apparent with visual presentation (83% in MS order; 85% in SM order). This result is consistent with Rummer and Engelkamp’s (2001) findings. The reduction of sentence recall appears to be attributed to phonological interference with auditorily presented word lists that followed the sentences. As seen Table 2 and 4, the accuracy of word recognition with auditory presentation in SM order is prominently higher than that in any other conditions. The enhancement of word recognition with auditory presentation can be
attributed to the presence of strong acoustic and phonological representations that are available with the auditory modality during the very short delay between the presentation of the memory list and the recognition test. Studies of list memory show an auditory advantage for the last couple items in the list (e.g., Conrad & Hull, 1968). Under RSVP, sentence recall was not affected by the following memory lists. The fact that there was no phonological interference under RSVP, however, does not imply that there is no phonological coding in sentence processing as Rummer and Engelkamp suggest. The evidence of phonological processing in sentences under RSVP is seen in intrusion rates.

Again a higher intrusion rate was obtained with SP than with S lures. It is noteworthy that the dramatic increase of intrusions occurred for auditory presentation, both with SP and S lures (20% and 21% of increase, respectively), while visual presentation did not give rise to such a big increase (2% of increase and 2% of decrease, respectively). The equal increases with both types of lure are attributed to phonological and acoustic interference from following list words. In the visual presentation, the interference was not significant and resulted in no effect of the sequential order. The large increase of intrusions only with auditory modality reflects more interference with auditory information from the following list words. Unlike in Experiment 1, there was no interaction between lure type and presence of lure. This seems due to the strong impact of phonological interference from following list words. There is still no doubt that the greater intrusions with SP than with S lure words was due to the phonological relatedness not due to any random factor.
Analyses of Serial Position Effects for Experiments 1 and 2

Potter and Lombardi suggested that a phonological store that underlies list recall would be too restricted in capacity to support the recall of sentences that are much longer than list span. However, reviewed studies suggest that phonological information persists for many more words than is evident in serial list recall. Exploratory analyses were carried out to determine if the difference between the SP and S targets was confined to the last few serial positions in the sentence or whether the effect could be detected much further back. Positions where targets appeared in sentences were divided into nine: first (F), second (F+1), third (F+2), fourth (F+3), end (E), second to end (E-1), third to end (E-2), fourth to end (E-3), and the rest (M). Figure 2 shows the distribution of target words in SP and S conditions according to the nine positions. As is in Figure 2, the proportion of targets at different serial positions was not well matched across the SP and

Figure 2

Distribution of Number of Target Words as a Function of Position in a Sentence
S conditions. Target words were not evenly distributed across the positions either on each type of lure. It is nevertheless worth looking at the pattern of intrusion over the different positions in a sentence as a basis for further investigation.

No targets appeared in the second to the end position, so this position has been omitted from Figure 3a to Figure 3d showing the percentage of intrusions with SP and S words. Four plots were made to compare the SP and S intrusions for the four modality by sequential order conditions. The intrusion rates that are plotted in Figure 3a to Figure 3d are the proportion of intrusions based on the number of the targets in each position. Overall distribution patterns in SP condition and S condition are either considerably different nor the same. In all of the graphs, much greater SP than S intrusions were found at the fourth from the end position. There also appear to be much greater SP than S intrusions at the first serial position as well. Given the unequal distribution of targets across positions and the fact that different targets appeared at different serial positions, strong conclusions cannot be drawn from these data. However, these preliminary findings suggest that phonological information may persist even from the beginning of the sentence for both auditory and visual presentation.
Figure 3

Distribution of Intrusion Rate with S & SP Words as a Function of Position in a Sentence
(From Exp. 1 & 2)

a. Memory List-Sentence Order with Visual Presentation

b. Memory List-Sentence Order with Auditory Presentation

c. Sentence-Memory List Order with Visual Presentation

d. Sentence-Memory List Order with Auditory Presentation
Experiments 1 and 2 provided powerful evidence of the involvement of phonological representations in immediate memory for sentences, as the intrusion rates with SP lures were higher than with S lures. Experiment 3 was conducted to examine the position effect and reinforce the findings from Experiment 1 and 2 by controlling the number of targets in different positions and by more closely matching the duration of the visual and auditory words in the memory lists. In addition, I attempted to address whether subjects notice the presence of lures and whether the awareness of lures influences intrusion if so. All variables considered in Experiments 1 and 2 (lure type, modality, and sequential order) were also included in Experiment 3.

EXPERIMENT 3

Method

Participants

Forty Rice undergraduates participated to fulfill their experiment participation requirement for introductory Psychology courses. All of them were native English speakers and naive about the experiment.

Materials

Forty sentences (20 in the SP condition and 20 in the S condition) were selected from the materials used in Experiments 1 and 2. These two sets of sentences were controlled for the same factors that were of concern in Experiments 1 and 2 including frequency, word length, concreteness, semantic similarity, and cloze rate (see Table 6). Five new versions of each sentence were constructed such that each had fourteen words
Table 6

Controlled Factors for Experiment 3

<table>
<thead>
<tr>
<th></th>
<th>SP (N = 30)</th>
<th></th>
<th>S (N = 30)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lure</td>
<td>Target</td>
<td>Lure</td>
<td>Target</td>
</tr>
<tr>
<td>Frequency</td>
<td>43</td>
<td>42</td>
<td>41</td>
<td>40</td>
</tr>
<tr>
<td>Word Length</td>
<td>8.3</td>
<td>7.8</td>
<td>7.7</td>
<td>8.2</td>
</tr>
<tr>
<td>Concreteness (1-7)</td>
<td>4.9</td>
<td>4.8</td>
<td>4.7</td>
<td>4.7</td>
</tr>
<tr>
<td>Cloze Rate (%)</td>
<td>41</td>
<td>10</td>
<td>39</td>
<td>9</td>
</tr>
<tr>
<td>Similarity (1-10)</td>
<td>7.2</td>
<td></td>
<td>7.5</td>
<td></td>
</tr>
<tr>
<td>Sentence Length</td>
<td>14</td>
<td></td>
<td>14</td>
<td></td>
</tr>
</tbody>
</table>

while keeping constant the target word, lure word, and five words of the memory list. Also, the meaning of the sentence was kept approximately constant across the five versions while varying the position of the target word. All the sentences had fourteen words and consequently there were fourteen possible slots where target words appeared. For simplicity, however, only ten slots were used as target positions and these ten slots were categorized into five positions - ‘beginning’, ‘near beginning’, ‘middle’, ‘near end’, and ‘end’. Target words appeared in either the first or second slots for the position of ‘beginning’, the fourth or fifth for ‘near beginning’, the seventh or eighth for ‘middle’, the tenth or eleventh for ‘near end’, and the thirteenth or fourteenth for ‘end’.

Design and procedure

The experiment was a five-factor design with sequential order, lure type, presence of lure, modality, and target position as independent factors. The visual presentation rate
of list words was 350 ms, instead of the 250 ms used in the previous experiment, to match the auditory presentation rate. Subjects were asked, at the end of the experiment, whether they had noticed anything about the relation of the words in the sentences and those in the memory lists. If they said yes, they were asked to specify what the relation was. Subjects were included in the aware group if they indicated that they notice three or more times that there was a semantic relation or a semantic and phonological relation between the words in the sentences and the words in the memory lists. All other aspects of the procedure were the same as in Experiments 1 and 2.

Results and Discussion

Word Recognition and Sentence Recall

The results of word recognition and sentence recall are detailed in Table 7. Recognition accuracy was higher in Experiment 3 than in Experiment 1 and 2, but the accuracy of sentence recall was slightly lower than in the previous experiments. There seem to be a tradeoff between recognition and sentence recall. That is, higher recognition led to lower sentence recall. The overall pattern does not seem to be significantly different from the previous experiments, thus no further analysis was carried out.

Intrusions

As presented in Table 8, a higher intrusion rate with SP words than S words was again obtained. Consistent with the previous experiments, more intrusions were made with auditory presentation than with visual presentation. More intrusions were also made when the memory lists followed the sentences than when the lists preceded the sentences. The overall increase of intrusion rates in SM order is mainly due to the enhancement of intrusions with auditory presentation when there were lure words in the memory lists.
Table 7

Percentage of Accurate Word Recognition and Sentence Recall from Experiment 3

<table>
<thead>
<tr>
<th>Presentation Order</th>
<th>Presentation Modality</th>
<th>Task</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Word Recognition</td>
</tr>
<tr>
<td>MS</td>
<td>Auditory</td>
<td>87</td>
</tr>
<tr>
<td></td>
<td>Visual</td>
<td>81</td>
</tr>
<tr>
<td>SM</td>
<td>Auditory</td>
<td>96</td>
</tr>
<tr>
<td></td>
<td>Visual</td>
<td>81</td>
</tr>
</tbody>
</table>

* MS: Memory List – Sentence order
* SM: Sentence – Memory List order

Table 8

Percentage of Intrusions of SP and S from Experiment 3 (N=40)

<table>
<thead>
<tr>
<th>Sequential Order</th>
<th>Presentation Modality</th>
<th>Stimulus Type</th>
<th>SP</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>With</td>
<td>Without</td>
</tr>
<tr>
<td>Auditory</td>
<td></td>
<td></td>
<td>25</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>With-Without</td>
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<td></td>
</tr>
<tr>
<td>MS</td>
<td>Visual</td>
<td></td>
<td>22</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>With-Without</td>
<td></td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Auditory</td>
<td></td>
<td></td>
<td>34</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>With-Without</td>
<td></td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>SM</td>
<td>Visual</td>
<td></td>
<td>22</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>With-Without</td>
<td></td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

*MS: Memory List – Sentence order
*SM: Sentence – Memory List order
Statistical analysis was carried out using a repeated measures ANOVA with five factors: lure type (SP vs. S), sequential order (MS vs. SM), modality (visual vs. auditory), presence of lure (presence vs. absence), and target position. Five main effects were found: lure type, $F_1(1, 38) = 35.72$, $MSE = 0.11$, $p < 0.001$, $F_2(1, 38) = 4.41$, $MSE = 0.86$, $p = 0.042$; presence of lure, $F_1(1, 38) = 63.11$, $MSE = 0.09$, $p < 0.001$, $F_2(1, 38) = 50.97$, $MSE = 0.11$, $p < 0.001$; sequential order, $F_1(1, 38) = 3.881$, $MSE = 0.21$, $p = 0.056$, $F_2(1, 38) = 6.23$, $MSE = 0.13$, $p = 0.017$; and modality, $F_1(1, 38) = 3.86$, $MSE = 0.167$, $p = 0.057$, $F_2(1, 38) = 5.40$, $MSE = 0.119$, $p = 0.026$. The new factor, position, showed a main effect as well, $F_1(1, 35) = 2.92$, $MSE = 0.15$, $p = 0.035$, $F_2(1, 35) = 2.53$, $MSE = 0.11$, $p = 0.058$. A significant interaction between sequential order and modality was obtained, $F_1(1, 38) = 7.30$, $MSE = 0.167$, $p = 0.01$, $F_2(1, 38) = 10.05$, $MSE = 0.12$, $p = 0.003$. There was also an interaction between sequential order and presence of the lure, $F_1(1, 38) = 10.31$, $MSE = 0.09$, $p = 0.003$, $F_2(1, 38) = 7.32$, $MSE = 0.12$, $p = 0.01$.

Thus, the results of Experiment 3 are consistent with those of the previous experiments for all aspects of main interest despite more stringent constraints on representation rate, sentence length and target position. A higher intrusion rate with SP words than S words was again obtained supporting the conclusion that phonological representations are stored in immediate sentence memory. The interaction of sequential order of sentence and memory lists with modality was due to overall more intrusions with the SM than MS order with auditory presentation but virtually no difference with visual presentation. This result also supports the notion that phonological representations are involved in immediate memory for sentences, since one would expect greater phonological interference from auditorily presented memory lists that follow the
sentences than from those that precede the sentence. Although spontaneous intrusions increased overall in SM order, the increase was greater when there were lure words in the memory list, which is confirmed by the interaction between sequential order and presence. It is perhaps not surprising that the lure words were more likely to be inserted into sentence recall when they followed the sentence compared to when they preceded it.

The intrusion rate with SP words with auditory presentation and SM order when the lure words were present is not as big as one would have expected based on Experiment 2. That is, there appears to be no difference between intrusions with SP words and intrusions with S words with auditory modality in SM order (34% vs. 33%) whereas there was a difference in the Experiment 3 (40% vs. 27). It should be noted that there was no significant three-way interaction between modality, order and lure presence in the present experiment, however. If this interaction proved significant in follow-up studies, one might hypothesize a strong impact of phonological interference with auditorily presented memory lists such that the phonological representations of the sentence were eliminated. The difference between Experiments 2 and 3 might be attributed to the closer matching of target position in Experiment 3.

The time course of memory for phonological information was of primary interest in this experiment. There was a main effect of position such that the highest percentage of intrusions was in the near end position and the lowest at the end position. However, the main effect of lure type and the failure to find an interaction between position and any other factors indicate that there are more intrusions with SP than S words in any position, independent of any other factors. The difference between intrusion rates with SP and S words reflects the phonological contribution to recall. Accordingly, the phonological
component was estimated by subtracting the intrusion rates with S words from the intrusion rates with SP words as depicted in Figure 4. From Figure 4, it is clear that phonological representations are present at any position in a sentence, thus encoding of phonological information occurs at all positions and is retained for all positions up to the point of recall.

Figure 4

**Distribution of Intrusion Rate Differences (with S Words – SP Words) as a Function of Position in a Sentence (From Exp.3)**

![Graph showing intrusion rates as a function of position.](image)

Figures 5a to 5d show the breakdown of intrusion rates in four combinations of modality and sequential order. Although some variations in the pattern of differences across different modalities and sequential order are apparent, the failure to obtain significant interactions between position and lure type and the other factors, indicate that these variations were not reliable.
Figure 5

Distribution of Intrusion Rate Differences (with S Words – SP Words) as a Function of Position in a Sentence (From Exp.3)

a. Memory List-Sentence Order with Visual Presentation

b. Memory List-Sentence Order with Auditory Presentation

c. Sentence-Memory List Order with Visual Presentation

d. Sentence-Memory List Order with Auditory Presentation
Target Word Recall

Accuracy of target recall when there was no lure word in the memory lists is depicted in Figure 6a and 6b. When there is no lure word, the differentiation between SP and S is no longer meaningful; thus, the data from the SP and S conditions were collapsed. From Figures 6a and 6b, it is clear that accuracy is higher with auditory presentation in MS order, whereas accuracy is higher with visual presentation in SM order. Interestingly, accuracy of target recall for words in the end position is higher than for those in the near-end position. Overall accuracy does not seem to be different in the two sequential orders.

Statistical analysis was conducted using a repeated measures ANOVA with three factors: sequential order (MS vs. SM), modality (visual vs. auditory), and target position. The dependent measure was accuracy of target word recall. The position effect was significant, $F_1(1, 35) = 8.47, \text{MSE} = 0.19, p < 0.001, F_2(1, 35) = 5.24, \text{MSE} = 0.23, p = 0.002$. An interaction between sequential order and modality was significant, $F_1(1, 35) = 7.87, \text{MSE} = 0.229, p = 0.008, F_2(1, 38) = 10.124, \text{MSE} = 0.18, p = 0.003$. No other effects were significant.

The pattern of target recall is that target words in the beginning position were recalled the best and accuracy of recall diminished gradually from the beginning to the end of the sentence. The interaction of modality and sequential order is interesting. With the memory lists preceding the sentence, the standard auditory advantage in recall was apparent. With the memory lists following the sentences, this pattern reversed with target recall better for visual presentation. This pattern indicates the power of an auditory list following the sentence, compared to a visual list, to impair memory for the sentence.
Figure 6

Accuracy of Target Words as a Function of Position in a Sentence (From Exp.3)

a. Memory List-Sentence Order

b. Sentence-Memory List Order
Awareness of Lure-Target Relationship

Half of the 40 subjects indicated that they had noticed that some words in the memory lists were semantically related to words in the sentences. Six of them were from the MS order and fourteen were from the SM order. The detectability of lure-target relations appeared higher with auditory presentation than visual in SM order and it appears to be related to the higher recognition of the word list with auditory presentation in SM, as seen in Table 9. The data were divided into the results for aware and unaware groups to investigate whether there was any difference between these two groups.

In terms of word recognition and sentence recall, there does not seem to be any obvious difference between the groups (See Table 9). Both groups show higher recognition accuracy with auditory presentation than visual presentation and higher recognition in SM order than MS order. The prominent finding throughout the three Experiments was that recognition with auditory presentation in SM order was much higher than in any other conditions. Both groups showed very high memory list recognition.

Aware and unaware groups displayed the same pattern of intrusion rates as well (see Table 10). Both groups showed the same pattern of the overall findings in all three experiments. More intrusions were made with SP words than S and when lures were present for both groups. SM order led to more intrusions than MS order in both groups. In conclusion, whether participants noticed the lure-target relationship did not affect word recognition, sentence recall, nor intrusion patterns.
Table 9

Percentage of Accurate Word Recognition and Sentence Recall: Aware vs. Unaware Subjects from Experiment 3

<table>
<thead>
<tr>
<th>Presentation Order</th>
<th>Presentation Modality</th>
<th>Task</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Word Recognition</td>
<td>84</td>
<td>74</td>
</tr>
<tr>
<td>Aware Group MS (N=6)</td>
<td>Auditory</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Visual</td>
<td></td>
<td>79</td>
<td>68</td>
</tr>
<tr>
<td>SM (N=14)</td>
<td>Auditory</td>
<td></td>
<td>96</td>
<td>78</td>
</tr>
<tr>
<td></td>
<td>Visual</td>
<td></td>
<td>79</td>
<td>79</td>
</tr>
<tr>
<td>Unaware Group MS (N=14)</td>
<td>Auditory</td>
<td>Word Recognition</td>
<td>84</td>
<td>76</td>
</tr>
<tr>
<td></td>
<td>Visual</td>
<td></td>
<td>77</td>
<td>70</td>
</tr>
<tr>
<td>SM (N=6)</td>
<td>Auditory</td>
<td></td>
<td>94</td>
<td>74</td>
</tr>
<tr>
<td></td>
<td>Visual</td>
<td></td>
<td>86</td>
<td>74</td>
</tr>
</tbody>
</table>

* MS: Memory List – Sentence order
* SM: Sentence – Memory List order
Table 10

Percentage of Intrusions of Aware vs. Unaware Subjects from Experiment 3

<table>
<thead>
<tr>
<th>Sequential Order</th>
<th>Presentation Modality</th>
<th>Subject Type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Aware</td>
</tr>
<tr>
<td></td>
<td>SP</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>(N=6)</td>
<td>(N=14)</td>
</tr>
<tr>
<td>Auditory</td>
<td>With</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>Without</td>
<td>16</td>
</tr>
<tr>
<td>MS</td>
<td>Visual</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>With</td>
<td>19</td>
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<tr>
<td>SM</td>
<td>Auditory</td>
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<td></td>
<td>With</td>
<td>23</td>
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<tr>
<td></td>
<td>Visual</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>Without</td>
<td>7</td>
</tr>
</tbody>
</table>
GENERAL DISCUSSION

The data from the three experiments clearly demonstrated that phonological representations are involved in immediate memory for sentences. The design of Experiments 1 and 2, reported here, are directly comparable to Experiments 1, 2, and 3 in Potter and Lombardi's (1990) study except that we included two types of lure words: semantically related words and semantically and phonologically related words. We replicated Potter and Lombardi's findings of greater semantic intrusions with semantically related lure words than with no lures present, indicating a role for semantic representations in immediate sentence repetition. Importantly, however, more intrusions were made with semantically and phonologically related lure words than with semantically related lure words, consistent with the findings of Katz (1998). The same result was obtained in Experiment 3, which had more tightly controlled materials and procedure than Experiments 1 and 2. Furthermore, Experiment 3 revealed that the higher level of intrusions for semantically and phonologically related lure words than semantically related lure words occurred for targets at all serial positions in the sentence, suggesting a longer duration of phonological representation in sentence memory than in list recall for unrelated words (i.e., 2 or 3 seconds according to Baddeley, 1990).

Another finding supporting the hypothesis of a role for phonological representations in sentence memory was the interaction between modality (auditory vs. visual) and sequential order of memory list and sentence presentation in Experiments 1 (MS) and 2 (SM). That is, a very high level of intrusions was observed with auditory
presentation and lists following the sentence. Also, target word recall was substantially lower when lists followed the sentence for auditory presentation. Both results suggest that the subsequent auditory list greatly disrupted the phonological representations from the sentence. These results are consistent with Rummer and Englekamp's (2001) findings. They, however, concluded that the interaction between modality and presentation order resulted because visually presented sentences were not stored in a phonological form because of the rapid presentation rate. Our findings of greater SP than S intrusions for visual presentation argues against this conclusion. One means of accommodating the interaction of modality and order together with evidence of phonological coding in the visual conditions it to appeal to a distinction between input and output phonological codes (see Martin, Lesch & Bartha, 1999). That is, auditory input is represented in terms of an input phonological code whereas visual input is recoded into an output phonological code. One would have to further argue that subsequent input phonological codes have a much greater interfering effect on previous codes than do subsequent output phonological codes.

One might argue that the higher intrusions with SP words does not result from the maintenance of phonological representations but instead, the maintenance of orthographic representations. Semantically and phonologically related words were selected in such a way that they shared the same first one or two phonemes with their target words (blast/blow, for example). Consequently, the SP words and their targets tend to share the same graphemes for the first one or two positions in the words. The orthographic account for the higher intrusions with SP words, however, seems implausible for several reasons. Certainly, in the auditory modality, there is little reason to suspect that subjects were
generating an orthographic code, yet the results for auditory presentation generally showed the same pattern as with visual presentation.

For visual presentation, there is a great deal of evidence for the automatic processing and generation of phonological codes from written materials (e.g., Colle & Welsh, 1976; Conrad, 1967; Levy, 1971; for reviews see Berent & Perfetti, 1995; Ferrand & Grainger, 1994; Lukatela & Turvey, 1994; Van Order, Pennington, & Stone, 1990; Ziegler & Jacobs, 1995). Phonology also has known to play a central role in visual word recognition (e.g., Carello, Turvey, & Lukatela, 1992, Lukatela, Lukatela, & Turvey, 1993; Lukatela, & Turvey, 1994; Rubenstein, Lewis, & Rubenstein, 1971; Van Orden et al., 1990). Automatic and strong phonological encoding has also been shown in languages such as Kanji of for which spelling does not provide any phonological information of the word (Erickson, Mattingly, & Turvey, 1977; Flaherty & Aidan, 1999). It was also observed in the current study that nearly all participants made lip movements to rehearse the visually presented materials. On the other hand, orthography does not appear to play a central role in word recognition other than to gain access to phonology and semantics (for a review see Grainger & Ferrand, 1996).

The time course of phonological and orthographic activation reinforces the notion that orthography subserves phonology and semantics. The clearest evidence of phonological and orthographic encoding has been provided by measuring priming effects with very brief visual masking in visual recognition (for review see Grainger & Ferrand, 1996). The experimental paradigm that has been widely adopted is that subjects complete lexical decision or perceptual identification tasks for a word/nonword immediately following a visual mask that is either phonologically or orthographically
similar to the target. Visual masking materials are exposed for a very brief period lest subjects detect a relationship between primes and targets.

Using a refined experimental design with which phonological and orthographic priming can be teased apart, the time course of phonological priming and orthographic priming were shown to be different. Orthographic but not phonological priming with nonwords are found at a short prime duration (35 ms) (Humphreys, Evett, & Taylor, 1982; Perfetti & Bell, 1991), whereas phonological priming effects start to emerge at longer prime durations (45-50 ms) (Ferrand & Grainger, 1992; Perfetti & Bell, 1991). Orthographic priming decreases as priming duration increases (Ferrand & Grainger, 1992, 1993) and at the 57 ms prime duration, the effect disappears (Grainger & Ferrand, 1996). These studies, in summary, have demonstrated a short duration for orthographic representations. This suggests the activation of orthographic representations subserve access other levels of representations such as semantic and phonological. In the current study, memory list words and sentence words were exposed much longer than in the studies of phonological and orthographical priming (250 ms/350ms and 200 ms, respectively)\(^1\). Furthermore, the interval between the exposure of memory list words and sentence words is a few seconds\(^1,2\). Thus, it is doubtful that orthographic similarity between lure words and their targets are the source of higher intrusions with SP words than S words.

One possible way to directly test the orthographic account is to use mixed modalities. That is, if list words are presented auditorily and sentences are presented visually, there would be no orthographic overlap between the target words and lure
words. If the same results are obtained, they would provide more direct evidence that phonological codes are involved even with visually presented sentences.

The Role of Phonological and Semantic Codes

Although the role of a phonological code was emphasized in the current study to counter Potter and Lombardi's claims, the results do not indicate that only a phonological code is involved. That is, the results also provided clear evidence of a role for semantic representations. In summary, the results of the current study support the notion that there are both semantic and phonological components in short-term memory for sentences.

Potter and Lombardi (1990) discounted a phonological contribution to sentence repetition. One interpretation of their position is that short-term memory is a separate system from a general language processing system. Studies using span-type tasks have reported evidence of the short retention of phonological representations: 3 to 6 items or the amount of material that can be rehearsed in 2 seconds (Baddeley, 1990). According to this view, it is not possible, as Potter and Lombardi argued, that short-lasting phonological representations can be held long enough to produce a 12 to 24 word sentence span.

How can we then explain the findings of the current study: semantic and phonological components and the long retention of phonological representations in sentences? It seems that all of the information a sentence can provide (i.e., semantic, phonological, syntactic, conceptual, etc.) can enhance the capacity of each level of representation. The long retention of phonological representations demonstrated in the
current study (at least 6 seconds) suggests that the capacity of the phonological store can be extended when there are other sources of information.

By adopting two notions that have been proposed within the past decade, a theoretical framework to encapsulate the current findings can be made. First, there are multiple components in short-term memory. Second, short-term memory for verbal materials (called verbal short-term memory thereafter) utilizes the same resources that underlie language processing. According to the second notion, verbal short-term memory reflects the characteristics of the language processing system. The characteristics relevant here include multiple levels of representations and interactive activation between these representations.

Theoretical Framework of Short-term Memory for Sentences

Multiple Components View of Short-Term Memory for Sentences

As reviewed in the introduction, Martin and her colleagues reported neurological patients who show a specific type of deficit in short-term memory for sentences in conjunction with the same type of deficit in span tasks (Martin & Romani, 1994; Martin, Shelton, & Yaffee, 1994). Specifically, patient EA shows a phonological deficit in the sentence repetition task in accordance with her phonological deficit in span tasks. AB, with a semantic short-term memory impairment, manifested the same semantic deficit in sentence repetition. In light of these findings, Martin and her colleagues have advocated a multiple components view of short-term memory for sentences that includes semantic, phonological, and syntactic components. They proposed that each component has its own system and separate capacities rather than a single capacity shared for different types
of information (for a contradicting view see Just & Carpenter, 1992). Their view further suggests that each of the components can be selectively damaged resulting in a specific type of deficit in short-term memory, as the examples above demonstrated. Each level of representations is suggested to interact with each other in spite of their autonomy. This interactive view is based on the assumption that verbal short-term memory is a subset of language processing system as will be discussed in the section: Interactive Processes between Multiple Representations.

**Verbal Short-Term Memory: Subset of Language Processing System**

Several researchers have acknowledged that verbal short-term memory is not a separate system but a mechanism governed by language processors exploiting different types of linguistic codes (e.g., Barnard, 1985; N. Martin. & Saffran, 1997; Monsell, 1984; Saffran, 1990; Shiffrin, 1993; for review see R. Martin. 1993). The view has been captured as follows: different levels of representations are generated over the time course of different tasks involving verbal materials (comprehension, production, repetition, etc) and those representations need to be stored transiently by the language processor. Verbal short-term memory is utilized for these representations (N. Martin & Saffran, 1997).

If this view is valid, there should be a relationship between patterns of short-term memory deficits and language impairments. Indeed, there are ample reports confirming this view. Patients with severe impairments in language inevitably show difficulty completing verbal short-term memory tasks (Heilman, Scholes, & Watson, 1976; Ostergaard & Meudell, 1984). Furthermore, the type of aphasia is reflected in short-term memory as the same type of deficit (Beeson, Bayles, Rubens, & Kaszniak, 1994; N.
Martin & Saffran, 1990; R. Martin, Shelton, & Yaffee, 1994; Risse, Rubens, & Jordan, 1984; Saffran, 1990; Trojano & Grossi, 1995). Verbal short-term memory seems to be more susceptible to brain damage than general language ability (e.g., Basso, Spinner, Vallar, & Zanobio, 1982; Vallar & Baddeley, 1984). The discrepancy between verbal short-term memory and general language ability can be accounted for by Martin, Lesch, and Bartha’s (1999) model that also assumes a strong linkage between verbal short-term memory and general language processing. According to their model, there are separate buffers for input and output phonological information as well as for lexical-semantic information. Within their model, the buffers can be disrupted while the language representations remain intact. However, because language representations feed into the buffers, a disruption of language representations will necessarily affect short-term memory.

**Interactive Processes of the Multiple Representations**

The language processor that is assumed to drive short-term memory capacity is “globally modular having separate semantic, lexical, morphological, phonological representations, but locally interactive between levels of representation” (N. Martin & Saffran, 1997, p.645). This interactive account is driven by Dell and O’Seaghdha’s (1992) interactive activation model. The model was originally proposed for language production, but has been applied to comprehension and repetition (N. Martin & Saffran, 1992; N. Martin et al., 1994; N. Martin, Saffran, & Dell, 1996).

The interactive activation model assumes bi-directional connections through which feedback and feedforward processes mediate the activation of semantic, lexical, and phonological nodes. In a production task, activation of semantic and lexical representations spread to and from phonological representations for a series of cycles.
until the activation of the sounds for output is complete. Repetition and comprehension
tasks are done in the same way except that the phonological representation is activated
first and the activation spreads to lexical and semantic levels of representation thereafter.

Although Dell and O'Seaghdha's model addresses processing of only a single
word, the principles of spreading interaction between different levels of representations
can be extended to sentence processing as well. The concept of spreading interaction can
be coupled with R. Martin and Romani's (1994) depiction of sentence comprehension:

The representations are assumed to be developing over time as the
sentence is presented. Thus, as each word is heard, the phonological form
is derived and the semantic and syntactic features of the words are
accessed. On a word-by-word basis, the syntactic structure is developed,
and as soon as the information is available for linking word meanings
together, propositions are derived. For word lists, only the first two
representational levels are available. For sentence comprehension, the top
level is most important. For sentence repetition, all levels may be
involved in reconstruction of the input. (p.521)

As discussed thus far, it is suggested that the source of the longer duration of
phonological representations in sentence memory is a property of language processing.
This general language processing account can easily account for the expanded capacity of
phonological representations with support from the other levels of short-term memory
(semantic, syntactic, etc.).
The Role of Phonological Representations in Sentence Comprehension

One question that might be rendered is what is the role of phonological representations, apart from semantic and syntactic representations, in sentence comprehension? This seemingly simple question has been open for quite a while and efforts to answer it have provided valuable insights into the nature of short-term memory for sentences. The view for the function of phonology seems to dramatically vary in the literature from being absolutely required to nearly unnecessary in sentence comprehension (for a review see R. Martin & Romani, 1994).

In the early literature, it was postulated that the phonological store is the primary vehicle for sentence comprehension. Jarvella (1971) maintained that the information of a sentence is retained in phonological form prior to the identification of each clause. Clark and Clarke (1977) also suggested a major role of phonology in sentence comprehension. In their four-step model of spoken language comprehension, they maintained that the first step of sentence comprehension is to store phonological representations on which the integration of the message is based. The view seems to be valid for most patients who have short-term memory deficits accompanying some sort of comprehension problem (Basso, Spinnler, Valar, & Zanobio, 1982; Caramazza, Basili, Koller, & Berndt, 1981; Friedrich, Martin, & Kemper, 1985; Warrington, Logue, & Pratt, 1971). The patient who has a short-term memory deficit accompanied by a difficulty in processing structural information suggests that syntactic analysis is based on phonological representations. It is intuitive that information containing a linear array of words should be referenced for a sentence to be comprehended.
Other literature suggests, however, that the integration of semantic information could be word-by-word (Marslen-Wilson, 1987; Marlen-Wilson & Tyler, 1980). That is, retention of phonological information is not crucial in sentence comprehension since a sentence can be comprehended as each word is perceived and processed. Additionally, data from patients whose language comprehension is normal in the presence of a severe short-term memory deficit (Butterworth, Campbell, & Howard, 1986; Campbell & Butterworth, 1985; Howard & Butterworth, 1989) drove the extreme position that phonological representations are not necessary in language comprehension.

There are situations, however, in which off-line linguistic integration is inevitable. Some researchers speculated that phonological retention is necessary for the comprehension of syntactically complex sentences. Patients with short-term memory deficits, indeed, generally show their difficulty in comprehending complex sentences (Caramazza et al., 1981; R. Martin, 1990; R. Martin & Feher, 1990; Saffran & O. Martin, 1975; Waters et al., 1991; Winson & Baddeley, 1993). Friedmann and Gvion (2002) pointed out that there was no conformity in the definition and manipulation of syntactic complexity used in these studies. Moreover, many of these studies also found no impairment of sentence comprehension in the presence of short-term memory deficits (Butterworth, Campbell, & Howard, 1986; Butterworth, Shallice, & Watson, 1990; Martin & Feher, 1990; Waters & Caplan, 1996; Waters et al., 1991). Accordingly, phonological storage in sentence comprehension does not seem to be for syntactic analysis. There does, however, seem to be a need for phonological short-term memory for off-line processes separate from syntactic analysis.
Friedmann and Gvion (2002) conducted a study with two types of Hebrew-speaking aphasics: agrammatic and conduction. Agrammatic aphasics often have a grammatical deficit in relative clause comprehension and conduction aphasics have difficulty in repetition tasks. The two types of aphasias, agrammatism and conduction, are attributed to different types of short-term memory deficits, syntactic and phonological short-term memory deficits, respectively (Friedmann & Givon, 2002). In their study, Friedmann and Gvion examined the interaction between the type of short-term memory deficits (syntactic and phonological) and the type of reactivation (syntactic and phonological) that is required during sentence comprehension.

Friedmann and Gvion (2002) examined syntactic reactivation using subject and object relative clauses; and phonological reactivation using lexically ambiguous words. Sentences required syntactic reactivation were created using subject and object relative clauses. Relative clauses, such as, “I met the girl that grandma drew _”, include a noun phrase (“the girl”) that is reactivated at the position of the gap (after “drew”) (Nicol & Swinney, 1989; Swinney, Ford, Frauenfelder, & Bresnan, 1988). The short-term memory demand for object relative clauses is higher than for subject relative clauses. The short-term memory load was manipulated by differing the intervening words between the head NP of the clause (antecedent) and the gap. A subject relative clause and an object relative clause are instantiated in (1) and (2), respectively.

(1) Ze baxur, im zakan she-ti-malbish et ha-xayal

This guy with beard that dresses ACC the-soldier

‘This is a guy with a beard that dresses the soldier.’
(2) Ze baxur, she-ha-yeled tofes t;

This the-guy that-the-kid catches

‘This is the man that the boy catches.’

Sentences requiring phonological reactivation were created using a lexically ambiguous word (antecedent) that initially leads to misinterpretation of the sentence and a word (gap) at which phonological reactivation of the antecedent is required to correct the misinterpretation of the sentence. The English examples for phonological reactivation are (3) and (4).

(3) The BASKET of the Hapoel player is packed with groceries.

(4) The BASKET of the famous basketball player from Hapoel Tel Aviv was

packed with grocery products.

The results of Friedmann and Gvion’s study (2002) showed that phonological short-term memory is not necessary for syntactic analysis. In picture matching tasks Agrammatic aphasics were not affected by the Gap-Antecedent Distance, but affected by sentence type (worse with objective clauses). In contrast, conduction aphasics were not affected by sentence type. Their comprehension was impaired for long Gap-Antecedent Distance when phonological reactivation was required. The authors interpreted the results to suggest that comprehension deficits occur only when the type of short-term memory deficit and the required reactivation are the same. That is, conduction aphasics’
phonological short-term memory deficit was coupled with a phonological reactivation requirement that caused their comprehension deficits.

CONCLUDING REMARKS

Different tasks have different goals and evoke different strategies according to their goals. A growing body of studies, however, suggests that verbal short-term memory for different tasks (comprehension, production & repetition, etc.; both a single word and a sentence) has the same underlying architecture and that the processes for different tasks may be the same (e.g., Damian & Martin, 1999; Martin & Freedman, 2000; Viglocco & Hartsuiker, 2002). With the same architecture (multiple components) and similar processes (interactive activity), short-term memory for various tasks may produce differential reliance on different components depending on the task goals.
Footnotes

1 The longest exposure for orthographic priming masks was found to be 100 ms in Ferrand and Grainger’s study (1992 & 1993). Most studies that attempted to show the orthographic components in written word processes had targets appearing immediately after the primes. The lack of studies with longer durations and intervals also suggests a very short duration (around 100 ms) of orthographic representations.

2 The shortest interval is about 500 ms in MS order when the lure word appears at the fourth position of the list and the target appears at the first position of the sentence. The longest interval is about 4 s in SM order when the target appears in the first position of the sentence and the lure appears in the last position of the list.

3 There was also a patient with a syntactic deficit (Martin & Romani, 1994).
References


subspan series of verbal and nonverbal items in Broca’s and Wernicke’s aphasia.

_Brain and Language, 22, 1-13._


Appendix A

Stimuli for Experiments 1 & 2

Semantically Related Condition: Sentences, Targets (underlined), and lures

The teacher gave the freshman class an extra credit assignment.
instructor

Having a home game requires a large quantity of work and money.
amount

The hotel offers its guests a variety of pleasures as well as its great facility.
amusements

There is a degree of resemblance between the two boys so they must be brothers.
similarity

His marriage outside their faith caused his parents a great deal of sorrow.
grief

The declaration of the royal birth was broadcast to the nation.
announcement

Her adversary left the tennis court in tears last Saturday.
opponent

Lots of lords and ladies in rich clothing danced all night at the castle.
apparel

The secret for their successful business is that they use high quality material for clothing goods.
fabric

He possesses a disposition that most people find very charming.
personality

Algeria regained its sovereignty after being a colony of France for hundreds of years.
independence

Anger filled the room when he made the derogatory comment about women.
fury

He couldn’t stand her arrogance at dinner and finally left the table.
haughtiness

The young man needed all his bravery to ask her to marry him.
courage

He didn’t like his mom’s friends and showed it with his insolence toward them.
rudeness

She is very mean but often times she shows benevolence toward the poor.
generosity
He enjoyed complete liberty to do as he wished before marriage.
freedom

Banishment from school is a hard form of punishment that nobody likes.
expulsion
He had to endure the public abasement of her scornful remarks.
humiliation

I checked so many times but the letter still had a spelling mistake.
error

The ship was sent into a severe storm and is now in great hazard.
danger

The employer is very happy to know that his plans meet your approval.
permission

They were in a state of weariness after climbing the mountain.
exhaustion

Joseph's brothers sold him to merchants and put him into bondage.
slavery

Due to injury to his brain he cannot reason normally any more.
damage

She felt a warm atmosphere at her first day of work.
environment

He swore an oath of devotion to the King and kept it until he died.
loyalty

The poor boy witnessed the homicide in front of him and was terrified.
murder

According to the weather forecast it will be cloudy and cold tomorrow.
prediction

The manager must deal with it in a businesslike fashion.
manner

The most attractive attribute of this dictionary is its handsome cover.
feature

Women were not given franchise in Britain until the twentieth century.
suffrage

Out of compassion for the homeless children he gave them shelter for the night.
sympathy

I can make a rough calculation of the number of bricks you will need.
estimate

We always believe that integrity is the best policy but we often forget it.
honesty
They made no **endeavor** to solve the problem but only complained about it. attempt

There is little **agreement** as to what our policy should be. consensus

People were amazed by all the authentic exotic food at the **feast**. banquet

It is a great **pain** watching him struggling with the problems he has. agony

**Semantically and Phonologically Related Condition: Sentences, Targets (underlined), and lures**

He has been a lifetime **advocate** of nuclear disarmament since the Hiroshima nuclear bomb. adherent

A major **catastrophe** was avoided when the plane stopped at the runaway. calamity

He has agreed to salary terms and is ready to sign a new **compact**. contract

The sales **department** is a major unit of our company. division

His obscene behavior at the party brought **disgrace** on his family. dishonor

He has been suffering from the rare bone **disorder** for a long time. disease

The heater’s **flame** ignited the blanket and burned the house. flare

Guards patrolled the **periphery** of the area to prevent the suspect from running away. perimeter

The **receiver** of any suspicious letters should report it to the police immediately. recipient

The gardener put a **stick** into the ground to support a young tree. stake

The prisoners of war survived starvation and **torture** at the hands of their captors. torment

**Investigation** of the body revealed two small insect bites on the arm. inspection

He showed little **respect** for the opinions of others on that matter. regard
The car stopped within a fragment of an inch of the wall.

Comparison of the two accounts revealed a great deal of disparity.

discrepancy

Finally only one competitor among many will be left for the heavyweight title.

contender

The country suffered intrusion by many surrounding countries due to its geographic location.

invasion

Her sudden arrest produced an immediate response from the press.

reaction

The athlete had a firm grasp on his racket for his blazing serve.

grip

The child was saved by the new medicine developed recently by scientists.

medication

He became unconscious when he received a severe blast on the head.

blow

Scientists are on the brim of a breakthrough in the treatment of cancer.

brink

Common salt for domestic use is a composite of sodium and chlorine.

compound

The boss gave great consideration to the suggestions that I made.

contemplation

Without adequate inducement the players don’t try very hard.

incentive

There was a short interlude halfway through the film.

intermission

Asian countries are not a good mart for automobiles due to lack of demand.

market

The bony projection on the surface of the skin was quite alarming.

protrusion

The dog was jumping around the tree with health and vivacity.

vigor

The victim of the crime was able to give a good depiction of the suspect.

description

The audience found the actress in the movie to be quite handsome.

actor

There is a front and a back entry to the building.

entrance
Finding the vaccine was the scientist's greatest accomplishment of the decade.

Admittance to the university depends on examination results, interview and other activities.

A test of his intellect found him to be the smartest man in the world.

The professor stood before the class and gave a lesson on organic chemistry.

We are working in combination with the police on this case.

I only like films that have plenty of action.

The couple did not expect acceptance of their unsuitable marriage from their parents.

Her unexpected arrival caused a great commotion last night.
Appendix A

Stimuli for Experiment 3

Semantically Related Condition: Sentences, Targets (underlined), and lures

Little agreement was made as to what our policy about the issue should be.
There was little agreement as to what our policy about the issue should be.
About the issue there was little agreement as to what our policy should be.
As to what exactly our policy should be virtually no agreement has been made.
As to what our policy about the issue should be there was little agreement.

consensus

The atmosphere that she felt at her first day of work was very warm.
She felt a warm atmosphere at her first day of work in the office.
In the office she felt a warm atmosphere at her first day of work.
At her first day of work she felt a warm atmosphere in the office.
At her first day of work in the office she felt a warm atmosphere.

environment

The attribute that makes this dictionary attractive is the splendid design on the cover.
The most attractive attribute of this dictionary is the splendid design on the cover.
For this dictionary the most attractive attribute is the splendid design on the cover.
The splendid design on the cover is the most attractive attribute of this dictionary.
For this dictionary the splendid design on the cover is the most attractive attribute.

feature

Benevolence toward the poor is often times shown by her although she is mean.
Often times she shows benevolence toward the poor although she is usually very mean.
She is mean but sometimes she shows benevolence toward the poor to my surprise.
She is very mean but quite often she shows benevolence toward the poor people.
She is very mean but surprisingly toward the poor she quite often shows benevolence.

generosity

Bondage was what Joseph faced after his brothers sold him to the merciless merchants.
They put him into bondage for a long time by selling him to merchants.
Joseph's cruel brothers put him into long bondage by selling him to merciless merchants.
Joseph's brothers sold him to merchants and put him into bondage for a while.
Joseph's brothers sold him to merchants and consequently put him into a long bondage.

slavery
A calculation must be made for the number of bricks that you will need. I must make a calculation for the number of bricks that you will need. I surely must make a rough calculation for the number of bricks you need. In order to find the number of bricks a rough calculation must be made. In order to find the number of bricks I must make a rough calculation.

estimate

The compassion he felt for the homeless children moved him to give them shelter. Out of warm compassion for the homeless children he gave them shelter that night. Toward the homeless children he felt warm compassion and provided them with some shelter. He decided to give shelter to the homeless out of compassion for the children. He decided to give shelter to the homeless children that night out of compassion.

sympathy

The declaration of the royal birth was broadcast to the nation by the press. The press broadcast the declaration of the royal birth to the nation without delay. Without delay the press broadcast the declaration of the royal birth to the nation. Without delay the press broadcast to the nation the declaration of the royal birth. Without much delay the press broadcast to the entire nation the royal birth declaration.

announcement

His devotion to the king was sworn and upheld until he died in war. He swore his devotion completely to the king and upheld it until he died. He swore an oath of complete devotion to the king and truly upheld it. To the king he swore an oath of strong devotion and surely kept it. He did everything for the king and his family to uphold his devotion completely.

loyalty

His disposition makes most people find him to be very charming and also cheerful. He possesses a disposition that makes most people find him to be very charming. Most people think that he possesses a disposition they find very charming and cheerful. Most people tend to agree how charming and cheerful his disposition is most days. Most days most people tend to agree how charming and cheerful his disposition is.

personality

A fashion that is businesslike should be used in dealing with the current problem. He must have a fashion that is businesslike in dealing with the current problem. The manager needs to have a businesslike fashion in dealing with the current problem. The manager must deal with the problem in a businesslike fashion and solve it. The manager must deal with the problem and solve it in a businesslike fashion.

manner
The feast in the hotel amazed the guests with all the authentic exotic food. The guests at the feast in the hotel were amazed by the exotic food. All the authentic exotic food at the feast amazed the guests of the hotel. The guests were amazed by the exotic food at the feast in the hotel. All the guests were amazed by all the authentic exotic food at the feast.

banquet

The hazard the ship faced is great because it was sent into a storm. The ship faces a hazard since it was just sent into a severe storm. The ship must face a great hazard because it was sent into a storm. The ship was sent into a severe storm and the hazard must be great. The ship was sent into a severe storm and it now faces great hazard.

danger

The homicide that the boy witnessed in front of him terrified him for years. The boy witnessed the homicide in front of him and was terrified for years. Last night the boy witnessed the homicide in front of him and was terrified. The poor boy was terrified because he witnessed the homicide in front of him. The poor boy was extremely terrified because last night he witnessed the terrible homicide.

murder

The injury to his brain caused him to not be able to reason normally. Due to his brain injury he is not able to reason normally any more. He cannot reason normally due to the injury to his brain many years ago. He cannot reason normally any more due to the unfortunate injury to his brain. He is not able to reason normally any more due to his brain injury.

damage

Quality material in their clothing is the secret to their success in the business. The use of quality material in their clothing is the secret to their success. Their business secret is to use quality material in their clothing all the time. The secret to their success is the use of quality material in their clothing. The secret to their success in the clothing business is to use quality material.

fabric

A mistake in spelling was still in the letter even after I checked it. There was a mistake in spelling in the letter even after I checked it. In the letter there was a spelling mistake even after I checked it carefully. I checked it many times but there was a spelling mistake in the letter. I checked it so many times but the letter still had a spelling mistake.

terror
The pain of watching him struggle with the problems is unendurable for us all. It is a great pain to watch him struggling with the problems he has. For all of us it causes great pain watching him struggle with his problems. Just watching him struggle with his problems causes great pain to all of us. For all of us watching him struggle with his problems is a great pain.

agony

The quantity of work and money required to host home games is almost overwhelming. A very large quantity of work and money is required to host home games. Hosting home games requires a large quantity of work and money during the season. During the season hosting home games requires a large quantity of work and money. During the season hosting home games requires work and money in very large quantity.

amount

The teacher gave the freshman class an extra credit assignment to improve their grades. To improve grades the teacher gave an extra credit assignment to the freshman class. To improve the freshmen's grades the teacher gave the class an extra credit assignment. To improve the grades of the freshman class the teacher gave an extra assignment. To improve the freshmen's grades an extra credit assignment was given by the teacher.

instructor

Action is what I usually enjoy in films so I like Hongkong style movies. I enjoy plenty of action in films so I usually like Hongkong style movies. I enjoy films that have plenty of action so I like Hongkong style movies. I like Hongkong style movies because of plenty of action which I enjoy greatly. I only enjoy Hongkong style movies because these films have a lot of action.

activity

The blast on the head knocked him down and caused him to become unconscious. He received a severe blast on the head and became unconscious for a while. Out of nowhere he received a severe blast on the head and became unconscious. He had become completely unconscious after he received a severe blast on the head. He became unconscious and did not know what was happening due to the blast.

blow

Major catastrophe was avoided when the plane stopped at the end of the runway. Fortunately a major catastrophe was avoided when the plane finally stopped on the runway. The plane managed to avoid major catastrophe when it finally stopped on the runway. The plane stopped on the runway and fortunately a major catastrophe could be avoided. When the plane stopped on the runway it managed to avoid a major catastrophe.

calamity
The compact is ready to be signed since he agreed to the salary terms. The newly made compact is to be signed since he agreed to the terms. He is ready to sign the new compact since he agreed to the terms. He agreed to the terms and is ready for the compact to be signed. He has agreed to the salary terms and is ready to sign the compact.

contract

The consideration the boss gave to the suggestions that I offered made me happy. The boss gave great consideration to the suggestions that my partner and I made. I am glad the boss gave great consideration to the suggestions that I made. The suggestions that I made received a great deal of consideration from my boss. To the suggestions that I made the boss gave a great deal of consideration.

contemplation

That department is a major unit of our company and has the largest staff. In our company that department is a major unit and has the largest staff. The largest staff is in the sales department because it is a critical unit. A major unit of our company is the sales department which is quite large. The largest and most critical unit in our company has been the sales department.

division

A depiction of the criminal suspect in great detail was given by the victim. The victim gave a depiction of the criminal suspect in great detail that morning. That morning the victim gave a good depiction of the criminal suspect in detail. The victim of the crime gave a very good depiction of the criminal suspect. That morning after the crime the victim was able to give the suspect's depiction.

description

The disorder in his bones has caused him excruciating pain for a long time. He has had some disorder in his bones and suffered excruciating pain for years. He has had a rare bone disorder and suffered excruciating pain for some time. Unfortunately he has suffered excruciating pain from the bone disorder for a long time. For a long time now he has suffered excruciating pain from that bone disorder.

disease

An entry open to everyone is in back in addition to the front one. There is another entry to the building in the back open to the public. There is a front and a back entry to the building open to everyone. The new department building has a front and a back entry open to everyone. The new department building has open to everyone a front and a back entry.

entrance
The flame of the heater ignited the blanket and the rest of the house. The hot heater's flame ignited the blanket and soon the house was on fire. The blanket was ignited by the heater's flame and the house caught on fire. The big fire started with the blanket ignited by the flame of the heater. The house caught on fire after the blanket was ignited by the heater's flame.

flare

His intellect test found him to be the smartest man in the whole world. A test of his intellect found him to be the smartest in the world. According to a test of his intellect he is the smartest in the world. He is the smartest in the world according to the intellect test he took. He is the smartest in the world according to a test of his intellect.

intelligence

The interlude halfway through the film was there because the movie was very long. There was a short interlude halfway through the film because it was very long. Halfway through the film there was an interlude because the movie was very long. Because the film was very long there was a short interlude halfway through it. Because the film was very long halfway through it there was a short interlude.

intermission

Intrusion into the country occurred frequently by many surrounding countries due to its location. The country suffered intrusion by many surrounding countries due to its great geographic location. Due to its location the country suffered intrusion by surrounding countries in the past. Due to its great geographic location the country suffered intrusion by many surrounding countries. Due to its great geographic location in the past the country suffered intrusion frequently.

invasion

The mart for automobiles in Asian countries is not expected to be very good. Indonesia isn't a good mart for automobiles due to the lack of high demand. Asian countries are not a good mart for automobiles due to lack of demand. Due to lack of demand Indonesia is not a good mart for automobiles anyway. Due to the lack of automobile demand Asian countries are not a good mart.

market

The medicine that the scientists recently developed saved the child from the fatal disease. The scientists developed the medicine that fortunately saved the child from the fatal disease. The child was saved by the medicine that was recently developed by the scientists. The child was saved from the disease by the medicine developed by the scientists. The scientists saved the child from the fatal disease by recently developing the medicine.

medication
The **periphery** of the area was patrolled by guards to find the criminal suspects. Guards patrolled the **periphery** of the area to prevent the suspects from running away. To find the suspects guards patrolled the **periphery** of the area all night long. To prevent the suspects from running away guards patrolled the **periphery** of the area. To prevent the criminal suspects from running away many guards patrolled the **periphery** area.

perimeter

The **receiver** of any suspicious letters should report them to the police without delay. Without any delay the **receiver** of suspicious letters should report them to the police. Suspicious letters should be reported by the **receiver** to the police without any delay. Suspicious letters should be reported to the police by the **receiver** without any delay. Any suspicious letters should be reported to the police without delay by the **receiver**.

recipient

A **response** to her sudden arrest was produced immediately by newspapers and other media. As expected an immediate **response** to her sudden arrest was produced from the media. Her sudden arrest produced an immediate **response** from newspapers and other media as expected. As we had expected her sudden arrest produced an immediate **response** from the media. Following her sudden arrest last night newspapers and other media produced an immediate **response**.

reaction

The **stick** that the gardener put into the ground was to support the tree. The gardener put a **stick** firmly into the ground to support the young tree. The wise gardener put a stout **stick** into the ground to support the tree. To support the young tree the gardener put a **stick** firmly into the ground. To support the young tree the gardener put into the ground a good **stick**.

stake

The **torment** and starvation were severe but all the prisoners of war survived them. During the war **torment** and starvation were severe but all the prisoners survived them. All the prisoners of war survived **torment** and starvation even though they were severe. All of the captured prisoners survived the severe starvation and **torment** during the war. During the war all of the captured prisoners survived the severe starvation and **torment**.

torture