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ABSTRACT

The assumption that phonological processes support comprehension guided two experiments in manipulating the similarity of the consonant code both within silently read sentences and between these sentences and concurrently vocalized phrases. The first experiment examined whether tongue-twisters would take longer to read than phonetically "neutral" sentences (those containing a natural mix of phonemes). The second experiment examined whether the phonological activation that occurs in reading is shared by vocalization. For example, reading a tongue-twister with many initial "t's" and "d's" might be additionally impaired by vocalizing phrases with alveolar consonants, "/d/" or "/t/." Results support the assumption that phonological processes are involved in at least some of the tasks of silent reading. However, the lack of a consistent interaction between consonant vocalization and specific tongue-twister sentences did not support the hypothesis that vocalization suppresses phonological codes used in reading. The lack of specific interference between concurrent vocalization and the reading task suggests that these automatically activated phonetic representations are not subvocal motor programs. In reading, concurrent vocalization may play a role similar to its role in memory. That is, it may impair reading not because it interferes with phonological activation, but because it requires capacity within a limited capacity cognitive system. (HOD)

LEARNING RESEARCH AND DEVELOPMENT CENTER

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The Visual Tongue-Twister Effect: Phonological Activation in Silent Reading

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We discuss the activation of phonological information during silent reading and report two experiments demonstrating a visual tongue-twister effect. Judgments of semantic acceptability took longer for sentences which repeated initial consonants or consonant pairs differing only in voicing such as /p/ and /b/ (tongue-twisters), compared with matched phonetically "neutral" sentences (those containing a natural mix of phonemes). In addition, concurrent vocalization with a tongue-twister phrase slowed performance, but did not produce reliable specific interference when the vocalization phrase repeated the same word-initial consonant (for example, bilabial /p/) as the sentences being read. We argue that the longer reading times for tongue-twisters is caused by interference due to the similarity of the phonetic representations automatically activated during reading. The lack of specific interference between concurrent vocalization and the reading task suggests that these automatically activated phonetic representations are not subvocal motor programs and that the concurrent vocalization paradigm is not an appropriate method to examine the phonological information used during reading.

At least since Huey's study of reading (1908/1968), the role of speech processes in silent reading has been an active research issue. Much work has addressed the plausibility of speech recoding *prior* to lexical access (Baron, 1973; Kleiman, 1975; Frederiksen & Kroll, 1976; Barron & Baron, 1977; Coltheart, Davelaar, Jonasson, & Besner, 1977; Davelaar, Coltheart, Besner, & Jonasson, 1978; Meyer & Ruddy, Note 1). Results have been mixed concerning this recoding issue (see McCusker, Hillinger, and Bias (1981) for a detailed review). However, it is possible that speech processes have their important role in skilled reading in automatic activation processes that are part of lexical access, but not necessarily prior to it. We have recently made this argument in some detail, suggesting how such activation processes might occur and how they would support comprehension (Perfetti & McCutchen, in press). Automatic activation is difficult to demonstrate but there is suggestive evidence from word vocalization tasks (Navon & Shimron, 1981), and backward visual masking research (Naish, 1980; Perfetti, Bell & McCutchen, Note 2).

On the other hand, there is evidence for the assumption that comprehension is supported by phonological processes. For example, comprehension of sentences, as reflected in verification times, is reduced by concurrent vocalization (Kleiman, 1975) and by phonological confusions within a sentence (Baddeley & Hitch, 1974; Baddeley & Lewis, 1981: Tseng, Hung, & Wang, 1977). However, concurrent vocalizations interfere with comprehension only when a fairly precise comprehension is required. Thus, following a series of studies, Levy (1975, 1977, 1978) reported that concurrent vocalization interfered with memory for wording but not for gist (Levy, 1978). Slowiaczek and Clifton (1980) added

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data to further modify this conclusion, showing that concurrent vocalization does interfere with comprehension, provided comprehension demands are great enough.

General Assumptions of a Model of Speech Processes in Skilled Reading

Even in those studies which assume phonological activation occurs during reading, the codes involved in this activation have not been explicitly described. It has been generally assumed (Kleiman, 1975; Levy, 1977, 1978; Slowiaczek & Clifton, 1980) that concurrent vocalization has its detrimental effect because speech mechanisms used in concurrent vocalization are used implicitly in reading (hence the term "suppression" in reference to this paradigm). However, a model of speech processes in reading does not need to assume the operation of some general all-purpose "speech mechanism." Neither must it assume that all vocalization interferes equally with reading. Instead, speech codes, both those used in speaking and those used in reading, may be specific for speech segments or even features of articulation. Thus, if words in the sentence being read activate the same phonetic code repeatedly, interference could result. Furthermore, if concurrent vocalization requires those same codes, then interference should increase as the items to be read become more phonetically similar to those being spoken.

Testing these hypotheses requires some assumptions concerning the nature of the linguistic codes and their role in the reading process. The following assumptions provide a broad framework for a model, discussed in more detail in Perfetti and McCutchen (in press). We assume that even when access to the lexicon is provided directly by the visual pattern of the printed word, a consequence of this lexical access is an automatic activation of some phonological features. This is not to suggest that the complete phonological representation of every word is activated. Such detailed phonological activation may require too much time to be a part of efficient reading. Specifically, we suggest that phonetic specification may be incomplete and biased toward the beginnings of words. In addition, since function words (e.g., determiners, prepositions, conjuctions) generally work as syntactic coordinators, they may not require such elaborate representation, neither semantically nor phonologically. Bradley (Note 3) had observed differences between function and content words in other reading tasks, and we intend what follows to apply only to the content words of sentences.

An abstract phonological representation containing information about the word-initial phoneme and general phonetic shape would be useful in reading, especially during the integration processes of comprehension. Together with abbreviated semantic information activated during the initial access of the lexicon, word-initial phonetic information could provide a concise index by which to reaccess specific words, if that became necessary during comprehension. Such a specific lexical index helps in retrieving a name and examining its specific semantic aspects within the context of a given sentence, a process we refer to as reference securing (Perfetti & McCutchen, in press).

We assume that the codes used in the activation of these phonological representations include some consonant features, rather than merely vowel sounds. The consonant assumption is made for two reasons. First, consonants carry more linguistic information than vowels. That is, consonants more specifically identify words, so consonants would be more helpful in securing specific lexical reference. Second, consonants do not have the acoustic duration that vowels do and so are more compatible with the speed at which silent reading can occur.

Finally, we assume that the consonant

code includes distinctive features of articulation. There is evidence that such features are part of memory for speech (Hintzman, 1967; Wickelgren, 1965, 1966) and also cues for perception of fluent speech (Cole, Jakimik, & Cooper, 1978). Other features, for example, voicing, might also prove important.

These assumptions guided the two experiments reported below. The experiments manipulated the similarity of the consonant code both within silently read sentences and between these sentences and concurrently vocalized phrases. The first manipulation results in visual tongue-twisters, that is, silently read sentences that repeat initial consonants across several words of a sentence. The rationale of the visual tongue-twister is as follows. As each succeeding lexical item is accessed, its abstract phonological representation is added to the others already stored in temporary memory. The phonological representations of words from tongue-twisters should be similar (especially at the important word-initial segment) and cause the kinds of similarity confusions often observed in memory tasks. Thus tongue-twisters should take longer to read than phonetically "neutral" sentences (those containing a natural mix of phonemes).

The second manipulation examined whether the mechanism of the phonological activation that occurs in reading is shared by vocalization. If the specific phonological code required during the silent reading of tongue-twister sentences is occupied by vocalization, then the reading of tongue-twisters should be additionally impaired by concurrent vocalization of a phrase which repeatedly activates the same code. For example, reading a *tongue-twister* with many initial *t*'s and *d*'s should be additionally impaired by vocalizing phrases with alveolar consonants, /t/ or /d/.

Experiment 1

The first experiment tested the tongue-twister hypothesis and the additional effects of concurrent vocalization. The tongue-twister hypothesis would be confirmed by longer acceptability judgments for sentences repeating a given word-initial consonant, or place of articulation. The possibility of specific phonetic interference from concurrent vocalization was tested by varying the phonetic content of the concurrent vocalization phrase. This specific interference would show itself either as increased times to judge the sentences or as disfluencies in the articulation of the vocalized phrase. To properly evaluate possible trade-offs in this dual task situation, both fluency on the vocalization task and performance on the sentence judgment task were measured.

To assess the specific phonetic interference between vocalizing and reading, a "control" phrase was used. This phrase contained only vowels so as to control for the general effect of concurrent vocalization, regardless of the phonetic content. The performance of subjects vocalizing the vowel phrase was used as a baseline to test for any effect specific to the phonetic similarity between the consonant vocalization phrases and the word-initial consonants of the sentences being read.

We assume the importance of phonetic codes in reading is in aiding reaccess to specific words in memory. Accordingly, interference between codes activated during reading and those activated during vocalization may increase as the reading comprehension task becomes more demanding. Thus, reading longer sentences might produce more interference than reading shorter sentences. The experiment also varied the length of the sentences to be read to test for an effect of memory load.

Method

Subjects. Subjects were 36 University of Pittsburgh undergraduates fulfilling class requirements. With the exception of approximate counterbalancing according to sex, the 36 subjects were randomly assigned to one of the three experimental conditions. The conditions differed according to which phrase the subject was to vocalize during the reading task. One group of twelve subjects vocalized a phrase filled with the word-initial bilabial consonant /p/ while reading, a second group vocalized a phrase filled with alveolar /t/, and a third group vocalized the vowel phrase /a/, /i/, /ai/, /o/, /u/.

Materials. The vocalization phrases, together with sample sentences from the reading task are presented in Table 1. Three sets of syntactically parallel sentences were constructed for the reading task. The parallelism was achieved by abstracting the syntactic frame used in a sentence in one set and repeating it in a sentence in each of the other sets. For example, one syntactic frame was (ADJECTIVE + NOUN + VERB + PREPOSITION + ARTICLE + NOUN). The sentence sets differed according to the nature of the word-initial consonants. One set of sentences repeated word-initial bilabial consonants (/b/ or /p/), and one set repeated word-initial alveolar consonants (/d/ or /t/). A third set of phonetically "neutral" sentences contained a natural mix of word-initial consonants, excluding both bilabials and alveolars. Each semantically acceptable neutral sentence was a semantic as well as syntactic match to either an acceptable bilabial or alveolar tongue-twister. That is, half the neutral sentences were paraphrases of bilabial tongue-twisters and half were paraphrases of alveolar tongue-twisters.

Half of the sentences in each set were semantically acceptable, and half were not. Meaningless sentences were constructed by rearranging content words across sentences within a given consonant type. Thus semantic anomalies were created while the meaningless sentences remained syntactically parallel to meaningful, acceptable

TABLE 1
EXAMPLES OF MATERIALS EXPERIMENT 1

Vocalization phrases		
	Vowel.	Ah ee I o ōō
	Bilabial	Pack a pair of purple pampers.
	Alveolar	Take a taste of tender turtle
Sentences in reading task		
	Short	
"yes"	Bilabial.	Both bags were in the box
	Alveolar	Twenty toys were in the trunk
	Neutral	Several games were in the chest
"no"	Alveolar	Tiny towel were in the trick
	Long	
"yes"	Bilabial	The press published the poem and promised to pay for permission
	Alveolar	The detective discovered the danger and decided to dig for details
	Neutral	The investigator found the hazard and chose to hunt for answers.
"no"	Bilabial	The puppies puzzled the peninsula and processed to please for paper
"yes"	Mixed Bilabial	The purpose of the play was to please the brave prince
	Mixed Alveolar.	The task of the device was to destroy the target territory
	Neutral:	The intention of the film was to entertain the noble king.

sentences. Due to this procedure, meaningless sentences generally required semantic analysis to reach a "no" decision, but some also contained a minor syntactic violation.

In addition, sentences were either short, three content words, or long, five or six content words. With all words counted, short sentences averaged six words and long sentences averaged ten words.

Thus there were three sets of short sentences—one of bilabial tongue-twisters, one of alveolar tongue-twisters, and one of neutral sentences—and three sets of long sentences—one bilabial, one alveolar, and one neutral. Each of the six sets contained 32 test sentences, 16 semantically acceptable and 16 unacceptable. In addition to the test sentences, there was a practice set of 24 sentences and three lead-in sentences to begin each test set.

Two blocks of sentences were created: one containing all of the long sentences and one containing all of the short sentences. Order of presentation of the blocks was counterbalanced across subjects. In addition, within each block the order of the three sets of sentences—bilabial tongue-twisters, alveolar tongue-twisters, and phonetically neutral sentences—was counterbalanced following a Latin square design.

Procedure. The subject's task was to read each sentence as it was presented on a CRT and, as quickly and accurately as possible, press a button marked "yes" if the sentence made sense or one marked "no" if it did not. The 24-sentence practice file acquainted subjects with the procedure. Presentation of sentences was under control of a PDP 11/15 computer, which controlled displays and recorded response times and errors. Response times were measured from the time the entire sentence came into view until the subject responded. The subjects began their vocalizations simultaneous with their keyboard response which brought the sentence into view. The vocalizations were recorded on a cassette recorder and scored for fluency.

Prior to the appearance of the first practice sentence, subjects practiced the vocalization phrase in isolation, and during the practice trials subjects were instructed to develop a comfortable rhythm in articulating the phrase. (This rhythm was used as a criterion for rhythm deviation in later scoring of vocalization fluency.) The instructions emphasized accuracy in the reading task as primary, but subjects were instructed to make their decisions as quickly as possible, as well as to fluently repeat their vocalization phrase.

Results of Experiment 1

In order to take into account any tradeoff between reading speed and vocalization accuracy, analyses were done on both latencies and a combined score which reflected the dual nature of the task (fluency/latency). Data were analyzed in a 3 (vocalization group) × 3 (sentence type) × 2 (sentence length) analysis of variance, with the last two factors repeated measures.

Latencies. Analyses of variance were done on response latencies for semantically acceptable and unacceptable items. Results for the semantically acceptable sentences are more interpretable, because subjects were required to read the whole sentence to make an "acceptable" judgment. Early negative decisions were possible for unacceptable sentences. Therefore, subject means of correct decision times for acceptable items of each sentence type and length are displayed in Table 2.

The main result of interest was that tongue-twisters required more time to verify than neutral sentences. The subject analysis of acceptable sentences revealed a main effect of sentence type, $F(2,66) = 10.04$, $p < .001$. A planned orthogonal contrast indicated that 95% of the variance of the main effect was due to the difference between neutral sentences (2.90 seconds) and tongue-twisters (3.08 seconds), $F(1,66) = 19.25$, $p < .01$. For acceptable sentences, the tongue-twister effect was not significant in the item analysis $F(2,90) = 1.57$, $p = .2$.

TABLE 2
DECISION TIMES FOR "ACCEPTABLE" ITEMS (SEC): EXPERIMENT 1

Vocalization group	Sentence length	Sentence type			Group mean
		Neutral	Bilabial	Alveolar	
Vowel	Short	2.72	2.49	2.79	2.67
	Long	3.57	4.08	4.05	3.90
Bilabial	Short	2.34	2.38	2.42	2.38
	Long	3.40	3.56	3.57	3.51
Alveolar	Short	2.23	2.35	2.35	2.31
	Long	3.14	3.45	3.41	3.34
Sentence type means		2.90	3.05	3.10	

However, for unacceptable sentences the tongue-twister effect was significant in both the subject analysis, $F(2,66) = 10.24$, $p < .001$, and the item analysis, $F(2,90) = 7.53$, $p = .001$. The difference between unacceptable tongue-twisters and neutral sentences accounted for 96% of the variance of the main effect of the subject analysis.

The subject analysis of acceptable sentences also showed that long sentences required more time than short sentences, 3.58 seconds compared with 2.45 seconds, $F(1,33) = 187.55$, $p < .001$. This effect was also significant in the item analysis, $F(1,90) = 185.10$, $p < .001$. For unacceptable sentences, the length effect was also significant, $F(1,33) = 125.02$ for the subject analysis, and $F(1,90) = 250.42$, $p < .001$ for the item analysis.

There was some evidence of a sentence type × length interaction such that the length effect was larger in tongue-twisters than neutral sentences and the tongue-twister effect was reliable for long sentences only. For acceptable items, this interaction was significant in the subject analysis, $F(2,66) = 7.02$, $p < .01$, but not in the item analysis, $F(2,90) = 2.00$, $p = .14$. However, for the unacceptable items, this interaction was not significant in either the subject analysis or in the item analysis.

Vocalization group was not significant in either the subject analysis of acceptable sentences, $F(2,33) = 1.67$, $p = .2$, or the analysis of unacceptable sentences, $F < 1$. However, the item analyses showed a main effect of vocalization group, both for acceptable items, $F(2,180) = 55.73$, $p < .001$, and for unacceptable items, $F(2,180) = 27.46$, $p < .001$. For the acceptable items, this effect was due to long times for the vowel vocalization group. For the unacceptable items, this effect additionally reflected shorter times for the alveolar vocalizing group.

Dual task measure. While the subject analysis showed a tongue-twister effect, none of the analyses of latencies showed specific interference between the consonant content of the tongue-twisters being read and the consonant content of the vocalized phrase. However, it was possible that processing trade-offs were occurring and that a dual task measure might provide evidence for specific interference between reading and vocalizing. The dual task measure reflected both response times, as reported above, and the subject's vocalization which had been recorded on a cassette recorder and scored for fluency.

This fluency score reflected both disfluencies in the subject's articulation of the phrase and nonrhythmic pauses in articulation. The fluency score was derived by assigning one of three possible points to the subject's vocalization during a reading trial. A vocalization trial was scored as 2 if it contained no disfluencies, as a 1 if it contained one disfluency, and as 0 if it contained two or more. Interjudge agreement of two judges in assignment of these scores was 90%.

The dual task measure was the ratio of a subject's total fluency score during presentation of a given sentence set to the mean decision time for that sentence set. An analysis of variance of this dual task measure (fluency/latency) showed some evidence of specific interference between the phrase the subject was articulating and the consonant content of the sentence he or she was reading. $F(4,66) = 2.68$, $p < .05$. To simplify the results of this analysis, Table 3 expresses performance on this measure as a ratio of performance on neutral sentences of a given length. The results are most simply seen in the overall summary at the bottom of Table 3. In contrast to control subjects, bilabial subjects did distinctly worse on both types of tongue-twisters compared with neutral sentences. More suggestive is that alveolar subjects did significantly worse on alveolar sentences, in agreement with the specific interference hypothesis.

Discussion of Experiment 1

The results of Experiment 1 demonstrated the visual tongue-twister effect. Before this can be accepted as a genuine phonetic effect, another explanation must be considered. This is the possibility that test sentences differed in their intrinsic sensibility and that the more sensible sentences were the neutral sentences. If so, the decision time differences might reflect ultimate sensibility differences, not the effect of consonant repetition. This possibility can be rejected. First, each neutral sentence was carefully matched, semantically and syntactically, to a tongue-twister. Second, data on the meaningfulness of the sentences were collected. An independent group of subjects rated each sentence for its meaningfulness on a five point scale. The variance of each item on this meaningfulness measure was taken to be an index of agreement concerning its acceptability. We considered this variance measure more sensitive to item differences than means across ratings. The mean of these variance scores for neutral sentences was .26, for bilabial tongue-twisters, .34, and for alveolar tongue-twisters, .69. This measure was used as a covariate in a new item covariance analysis of latencies. The results of this analysis replicated the pattern we have reported for the item analyses of latencies. There was a significant tongue-twister effect for unacceptable items, $F(2,89) = 5.94$, $p < .01$, and a nonsignificant difference for acceptable items, with

TABLE 3
DUAL TASK PERFORMANCE EXPRESSED AS PROPORTION OF DUAL TASK MEASURE ON CONTROL SENTENCES: EXPERIMENT 1

Vocalization group	Sentence length	Sentence type		
		Neutral	Bilabial	Alveolar
Vowel	Short	1.00	1.07	.98
	Long	1.00	.88	.98
Bilabial	Short	1.00	.96	.91
	Long	1.00	.95	.95
Alveolar	Short	1.00	.88	.83
	Long	1.00	.93	.80
Overall summary				
	Vowel		.99	.98
	Bilabial		.96	.92
	Alveolar		.90	.82

judgments of neutral sentences requiring less time, $F(2, 89) = 1.54$, $p = .2$.

Several questions remained, however, after Experiment 1. Of major importance was the lack of specific interference for the bilabial group. These subjects showed only a general tongue-twister effect and not a specific vocalization interference effect. With only one group of the subjects showing specific interference, and then *only* in the dual task measure, specific interference effects were much in doubt. We also thought it necessary to replicate the tongue-twister effect on an expanded set of items and to demonstrate a consistent effect across items as well as subjects. These considerations prompted Experiment 2.

Experiment 2

The second experiment differed from the first in three ways. First, since the variance among subject groups was large in Experiment 1, vowel versus consonant vocalization was made into a partially within-subject factor in the second study. Each subject vocalized a vowel phrase and a consonant phrase and thus became his own control. Second, the vowel phrase, which proved so difficult for subjects in Experiment 1, was changed from /a/, /i/, /ai/, /o/, /u/ to a meaningful phrase ("I owe you an I.O.U."). This was done to reduce both memory load and interference from the familiar phrase that names the letters A, E, I, O, U. Finally, a third type of tongue-twister and its corresponding vocalization were added. This addition involved the velar consonants, /k/ and /g/. With this addition, there were three sets of tongue-twisters, as well as three consonant vocalization groups within which to detect specific interference.

Method

Subjects. Subjects were 48 University of Pittsburgh undergraduates fulfilling class requirements. With the exception of counterbalancing according to sex, the 48 subjects were randomly assigned to one of three experimental conditions, 16 in each. (Because the critical data depended on accurate sentence decisions, subjects with error rates over 25% were replaced. This resulted in the replacement of 25 subjects, distributed rather evenly across the three conditions.) Each condition differed according to which consonant phrase the subject was to vocalize. Thus, there were three subject groups: one vocalizing the vowel and bilabial phrases, one vocalizing the vowel and alveolar phrases, and a third vocalizing the vowel and velar phrases.

Materials. Four sets of 40 sentences were constructed, incorporating sentences from Experiment 1 when appropriate. Only sentences containing five or six content words were used. In one of the sets, each sentence contained five or six content words beginning with bilabial phonemes (/b/ or /p/). Another set was filled with word-initial alveolar phonemes (/d/ or /t/), and a third with word-initial velar phonemes (/g/ or /k/). The fourth sentence set contained phonetically neutral sentences with a natural mix of word-initial consonants, excluding bilabial, alveolar, and velar consonants. The sentences were again constructed as syntactic parallels: a syntactic pattern used in one sentence of a given consonant set was repeated in a sentence in each of the others. As in Experiment 1, half of the sentences in each set were semantically acceptable and half were not. Unacceptable sentences were constructed as in Experiment 1, interchanging content words across sentences within a given consonant type. Syntactic acceptability was preserved as much as possible in the unacceptable sentences to ensure a semantic basis for the judgment. Each of the 20 acceptable phonetically neutral sentences was a semantic as well as a syntactic parallel to a tongue-twister. The tongue-twister sets were represented as equally as possible in the set of matched neutral sentences: 7 of the acceptable neutral sentences were phonetically neutral paraphrases of bilabial tongue-twisters, 7 were neutral paraphrases of alveolar tongue-twisters, and 6 were neutral paraphrases of velar tongue-twisters. Examples of the vocalization phrases and sentences used in Experiment 2 are presented in Table 4.

The four sets of 40 sentences produced a total of 160 sentences, which were read by all subjects. These were presented in two blocks of 80 sentences each. Each block contained 20 sentences (10 acceptable and 10 unacceptable) from the phonetically neutral set and 20 from each of the sets of tongue-twisters—bilabial, alveolar, and velar. Within blocks, each sentence set began with a lead-in sentence, and a practice set of 21 sentences was constructed which preceded the experimental blocks during presentation. In order to make vocalization a within-subject variable, each subject saw one block of sentences while vocalizing the vowel phrase and the other block while vocalizing the consonant phrase. In addition, order of presentation of the sentence sets within blocks was counterbalanced across subjects, following a Latin square design. Order of presentation of block and vocalization was also counterbalanced. Thus each of the 48 subjects represented a unique combination of consonant vocalization, block order, vocalization order, and order of the sentence sets within each block (3×2×2×4).

In order to evaluate the possibility of differences in intrinsic meaning of sentences within and across sentence sets and to equate the blocks as much as possible, the test sentences were rated on a five point comprehensibility scale by an independent group of subjects under no time constraint. These subjects were instructed to rate a sentence as a 5 if it made perfect sense, as a 1 if it was total nonsense, and as a 3 if they could not decide whether it made sense. (Very few sentences were rated as 3, and those that were so rated were rewritten.) The variance of each item on this meaningfulness measure was again taken to be an index of agreement concerning its acceptability. The mean of these variance scores for neutral sentences was .37 (SD = .39), for bilabial tongue-twisters, .54 (SD = .30), for alveolar, .51 (SD = .43), and for velar, .49 (SD = .37). In an analysis of variance, tongue-twisters were not different from neutral sentences, $F(3,156) = 1.67$, $p = .18$. Based on these ratings, the two blocks of sentences were constructed so as to be approximately equal in the number of sentences rated 5, 4, 2, and 1 that they contained.

Procedure. The procedure was the same as in Experiment 1, except that the subjects vocalized two phrases, one for the first block of 80 sentences, and a second phrase for the remaining block of 80 sentences. Half of the subjects vocalized the vowel phrase first, and half vocalized their consonant phrase (bilabial, alveolar, or velar)

TABLE 4
EXAMPLES OF MATERIALS, EXPERIMENT 2

Vocalization phrases		
	Vowel.	I owe you an I.O.U.
	Bilabial.	Pack a pair of purple pampers.
	Alveolar	Take a taste of tender turtle
	Velar	Catch the crumbs of cocoa cookies.
Sentences in reading task		
"yes"	Bilabial.	The bronze bars were brought in bags to the bank.
	Alveolar.	His tall tales were taken as truth by the twins.
	Velar	T' gas cans were claimed as the cause of the crash
	Neutral.	... exaggerated stories were believed by his sons.
"no"	Velar.	The ground clothes were concentrated as the cart of the code.

first. Subjects read each sentence and judged its semantic acceptability, pressing the appropriate button as soon as a decision had been made. Each subject's concurrent vocalization was recorded on a cassette recorder, and response latency as well as accuracy of the acceptability judgments were recorded by the computer.

Results of Experiment 2

Analyses were done on latencies, errors, fluency, and on the combined score described previously (fluency/latency). Acceptable sentences were analyzed separately from unacceptable sentences, as well as combined.

Latencies. The results of interest from the analysis of reading speed were these: (1) tongue-twisters required more time to verify than neutral sentences; (2) latencies were longer during vocalization of the consonant phrase than the vowel phrase; (3) there was no evidence of a specific interaction between consonant vocalization phrase (bilabial, alveolar, or velar) and tongue-twister sentence type.

The tongue-twister effect was significant in the subject analysis of acceptable and unacceptable sentences combined, $F(3,126) = 9.13$, $p < .001$. The comparison between tongue-twisters and neutral sentences accounted for 98.6% of the variance of the main effect, $F(1,126) = 27.01$, $p < .01$. The tongue-twister effect was also significant in the analysis of acceptable sentences only, with 3.10 seconds required to judge acceptable tongue-twisters compared with 2.72 seconds for neutral sentences, $F(3,126) = 13.06$, $p < .001$. The comparison between tongue-twisters and neutral sentences accounted for 95% of the variance of the main effect, $F(1,126) = 37.32$, $p < .01$. The tongue-twister effect was also significant across items, regardless of whether acceptable sentences were analyzed alone, $F(3,72) = 7.58$, $p < .001$, or combined with unacceptable sentences, $F(3,152) = 7.09$, $p < .001$. In the analysis of unacceptable sentences only, the tongue-twister effect was only marginal, $F(3,126) = 2.33$, $p = .08$. (There was, in general, much more variability in the unacceptable sentences in the subject analyses, probably due to variable "exit rules" that allowed subjects to terminate processing when they read a semantic anomaly, regardless of its position in the sentence.)

Subject analyses also showed a significant effect of vocalization phrase. Judgments of acceptable sentences were longer during vocalization of the consonant phrase than the vowel phrase, 3.15 seconds compared with 2.87 seconds, $F(1,42) = 7.48$, $p < .01$. The vocalization effect remained significant in the subject analysis of acceptable and unacceptable sentences combined, $F(1,42) = 4.60$, $p < .04$. However, it failed to reach significance in the subject analysis of unacceptable sentences only, $F(1,42) = 1.60$, $p = .2$, despite a 170-millisecond difference between means.

In none of the subject analyses was there a significant specific interaction between consonant vocalization and tongue-twister sentence type, $F < 1$ in all subject analyses. The item analysis of acceptable sentences also showed no interaction, $F < 1$.

These results are summarized in Table 5, which displays subject means for acceptable sentences. The main effect of sentence type, the visual tongue-twister effect, is seen in row 4. The tongue-twisters required an average of 370 milliseconds longer to process than phonetically neutral sentences.

Errors. In the subject analysis of errors on acceptable sentences, the tongue-twister effect was again significant, $F(3,126) = 3.86$, $p = .01$, with the difference between tongue-twisters and neutral sentences accounting for 55% of the variance of the main effect, $F(1,126) = 6.37$, $p < .03$. In this analysis, however, the vocalization effect (vowel or consonant) was not significant, $F < 1$.

Fluency. Since this measure is appropriate only in analyses of subject performance over entire sets of sentences, only a subject

TABLE 5
DECISION TIMES FOR "ACCEPTABLE" SENTENCES (SEC), EXPERIMENT 2

Vocalization group	Vocalization	Sentence type: Neutral	Bilabial	Alveolar	Velar	Group mean
Bilabial/	Vowel	2.50	2.86	2.93	2.79	2.77
Vowel	Consonant	2.71	3.18	3.08	3.10	3.02
Alveolar/	Vowel	2.30	2.76	2.67	2.90	2.66
Vowel	Consonant	2.65	3.06	2.94	3.02	2.92
Velar/	Vowel	2.79	3.27	3.28	3.34	3.17
Vowel	Consonant	3.36	3.57	3.36	3.71	3.50
Sentence type means		2.72	3.11	3.04	3.14	
Vocalization means	Vowel					2.87
	Consonant					3.15

analysis is reported. While the analysis of errors showed only a tongue-twister effect and no vocalization effect, the fluency analysis showed only a vocalization effect and no tongue-twister effect, $F < 1$. Subjects made fewer disfluencies during the vocalization of the vowel phrase than the consonant phrase, $F(1,42) = 29.75$, $p < .001$. There was also a significant interaction between vocalization and order of vocalization, $F(1,42) = 4.85$, $p < .04$, such that vocalization of the vowel phrase showed even fewer disfluencies after practice with initial vocalization of the consonant phrase.

Dual task measure. The analysis of the combined measure (fluency/latency) did not reveal specific interference from concurrent consonant vocalization in any group. The pattern of results was unchanged from the latency analyses. The tongue-twister effect remained, $F(3,126) = 11.09$, $p < .001$, with neutral sentences compared with tongue-twisters, $F(1,126) = 31.08$, $p < .01$, accounting for 93% of the variance of the main effect. Also remaining was the vocalization effect, $F(1,42) = 10.08$, $p < .003$.

Discussion of Experiment 2

Experiment 2 confirmed the tongue-twister effect with all three sets of tongue-twisters and showed the robustness of the effect across subject and item ...ies. In order to further test whether the tongue-twister effect was genuinely phonetic, we compared performance on the neutral sentences with the specific tongue-twisters with which they were both semantically and syntactically matched. This analysis was performed to make certain that those tongue-twisters which were not matched in meaning to a neutral sentence were responsible for the tongue-twister effect. This analysis of semantically matched items confirmed the tongue-twister effect. Tongue-twisters required a mean of 3.14 seconds to verify, while the matched neutral sentences required significantly less time, 2.84 seconds, $F(1,38) = 6.39$, $p < .02$.

Still another nonphonetic explanation could be offered for the tongue-twister effect. Perhaps the repetition of the same grapheme in word-initial positions makes the sentence visually confusing, quite apart from its phonetic content. Some tongue-twisters did contain word-initial repetitions of a single grapheme, for example, (1) *The dark drifts of the desert were dry and dusty.* However, others contained only word-initial repetitions of place of articulation with the graphemes more variable, for example, (2) *The tired, dirty donkey turned toward the door.* The voiceless velar /k/ provides an interesting case, since it has three different spellings in English. The word-initial phoneme could, therefore, be repeated while the graphemes changed, for example, (3) *The curved claws of the kitten were clean and quick*.

In order to examine whether the tongue-twister effect was due to phonetic repetitions or letter repetitions (as Baddeley and Lewis (1981) suggested), a post-hoc analysis of variance was performed on a subset of the items. Sentences with 100% of the content words containing the same word-initial phoneme and grapheme, such as (1), were compared with sentences containing content words with mixed initial graphemes, such as (2) and (3). The criterion for the mixed classification was that a maximum of three of the five or six content words (up to 60%) contain the same initial grapheme. According to this criterion, 46 of the 60 tongue-twisters used in Experiment 2 were analyzed. The 14 sentences in which more than 60% but less than 100% of the content words began with the same grapheme were excluded from this analysis, so as to make the same-grapheme and mixed-grapheme sets as different as possible. The difference between the mean latencies for the same-grapheme sentences (3.11 seconds) and the mixed-grapheme sentences (2.97) was not significant, $F < 1$.

The suggestion by Baddeley and Lewis (1981) that phonetic similarity effects are due to visual confusions is in contradiction to our explanation of the tongue-twister effect. In Baddeley and Lewis (1981) and other related experiments (Baddeley & Hitch, 1974), phonetic similarity was manipulated by repeating vowel–consonant pairs throughout a sentence, that is, sentences were filled with rhymes. Rhyming sentences required longer reading times in a semantic acceptability task. Baddeley and Lewis (1981) also found that counting aloud did not interact with rhyming-based phonetic similarity in either latencies or errors. They concluded that the phonetic similarity effect was due not to phonetic repetition but to *visual* repetition in the sentences containing rhymes. They found support for this conclusion in correlations ($r = .6$) between sentence judgment times and a visual repetition measure based on the number of repeated digrams in a sentence.

While our comparison of same-grapheme and mixed-grapheme tongue-twisters did not show a significant difference between the two types, there was a difference in the direction predicted by the visual confusion hypothesis. We further assessed visual similarity in a manner comparable to Baddeley and Lewis (1981). The number of repeated digrams was counted in each of the acceptable sentences from Experiment 2. Following Baddeley and Lewis (1981) this digram count included all the graphemes in a word (not only word-initial graphemes) and all the words in a sentence (function as well as content words). Since sentence length is correlated with reading time, each sentence's digram count was corrected for sentence length by dividing the number of repeated diagrams by the number of words in the sentence. The corrected digram score for each sentence was then correlated with the average reading time for that sentence. For all sentences, this correlation was not significant, $r = .18$, $p = .11$. For the tongue-twisters separately, this correlation was zero, $r = .03$, whereas for the neutral sentences separately, it was modest and in the direction predicted by a visual hypothesis, $r = .40$, $p = .08$. Thus whatever modest effect there was, due to digram repetition, it was clearly not responsible for the tongue-twister effect. We conclude that our effect is phonetic.

A significant difference between the present experiments and those of Baddeley and Lewis (1981) may partly account for the differences in the role of visual similarity. Baddeley and Lewis (1981) used rhymes which contained repetitions of vowel–consonant pairs and which were often represented by the same grapheme pair. Our tongue-twisters, however, repeated word-initial phonemes only, sometimes varying the grapheme—/c/ or /k/—and often repeating place of articulation only, not the phoneme—/t/ and /d/, for example. While our tongue-twister effect is not due to grapheme repetitions, the source of the similarity effect observed in rhyming sentences by Baddeley and Lewis (1981) and Baddeley and Hitch (1974) remains unclear.

General Discussion

The visual tongue-twister effect supports the assumption that phonological processes are involved in at least some tasks of silent reading. However, the lack of a consistent interaction between consonant vocalization and specific tongue-twister sentences does not support the hypothesis that vocalization "suppresses" phonological codes used in reading. By this hypothesis the vocalization of a phrase repeating word-initial alveolar phonemes, for example, should cause specific impairment of performance on tongue-twisters with repeated word-initial alveolar consonants. There was no evidence of such specific impairment in Experiment 2. In Experiment 1, one of the two consonant vocalization groups showed specific interference, but only on the combined measure (fluency/latency). At this point, then, only one group out of five has shown a statistically significant interaction, and none in reading times alone.

These results raise some interesting questions. We have argued that the visual tongue-twister effect reflects phonological processes specific to the phonetic content of the words being read, especially the word-initial place of articulation. On the other hand, there is no evidence that specific phonetic interference is produced by vocalizing. We are left with two theoretical choices in explaining this pattern of results. One is that our hypothesis that silent reading involves specific phonetic processes is incorrect. The second is that the concurrent vocalization task does not tap the specific speech processes important in silent reading. We will argue that the latter is the correct conclusion. First, we will briefly reexamine our hypothesis that silent reading activates specific phonetic information, or what we will call the code assumption.

The Code Assumption and the Tongue-Twister Effect

There is certainly no claim that word-initial consonants are the only part of the phonetic code in silent reading. We did assume, however, that such consonants are an important part of the code. Relative to vowels, consonants are high in information value and they have discrete linguistic value as opposed to the strictly acoustic value that vowels have. And, relative to medial segments, initial segments are highly informative and likely to be activated during lexical access. The visual tongue-twister effect does suggest that speech processes in reading may include this sort of code information. Sentences containing specific phoneme or place repetition required more time to read silently. We have argued that this difficulty may result from confusions and reprocessing during the securing of specific lexical references. (See also Perfetti and McCutchen, in press.) In temporary memory, the abstract and abbreviated phonemic representation that is sufficient to distinguish one word from another in normal phonemically mixed sentences is not sufficient in tongue-twisters. Since all the content words of tongue-twisters begin with the same consonant (or with consonants sharing place of articulation), their abstract phonological representations—which are automatically activated—are similar, especially at the important word-initial segment. Interference thus results. In order to perform the sentence reading task, subjects must reprocess the words and obtain more complete word information from memory.

An essential feature of our hypothesis is that the speech processing effects in silent reading include automatic processes, not easily subject to control. We can offer no empirical proof of this assumption. However, if this assumption is correct, some of the apparent discrepancy between the positive tongue-twister results and the negative concurrent vocalization results is explained, as we suggest below.

What Does Vocal Suppression Suppress?

The concurrent vocalization paradigm is based in part on the assumption that overt vocalization interferes with covert phonological activation, or "recoding," and impairs reading to the extent that this recoding is necessary in the reading task. This is why failures to find such interference effects is taken as evidence against phonological processes in reading (Baddeley & Lewis, 1981; Levy, 1978). This assumption stems, at least in part, from the detrimental effect that overt vocalization was found to have on performance in short-term memory tasks (Murray, 1968). However, the data from the studies presented here suggest that the vocalization effects evidenced in reading tasks are qualitatively different from those in short-term memory tasks.

The tongue-twister effect suggests that phonological information is activated during silent reading, even when it hinders performance. This activation appears to be automatic, rather than strategic. If phonological activation were an optional strategy, one would think that subjects would have abandoned it when faced with phonologically confusing sentences and dealt solely with the meaning of the sentences. Our subjects were not able to abandon their phonological "strategy," as it is often called (Barron, 1981; McCusker et al., 1981). The activation of phonological information, we suggest, is not a strategy or at least not an easily controlled one. Instead, it may be a process automatically activated during silent reading, at least in reasonably skilled adults.[1]

This automaticity may be the difference between the phonological information activated during reading and the recoded phonological image used during rehearsal in memory tasks. This difference may explain the effects that concurrent vocalization has in reading compared with short-term memory tasks. Full phonological recoding of the sort employed in memory tasks is an optional rehearsal strategy that may or may not be abandoned, according to task demands. Concurrent vocalization encourages its abandonment. When subjects must simultaneously vocalize during a reading task, they cannot subvocally rehearse items, and phonologically similar items no longer produce more errors (Murray, 1968). By contrast, concurrent vocalization did not eliminate phonological confusions in the present studies nor in previous reading studies employing phonologically similar material (Baddeley & Hitch, 1974; Baddeley & Lewis, 1981). It should be noted, however, that in Murray's (1968) memory task, the effect of concurrent vocalization was to decrease recall of the phonemically nonconfusing list to the low level of recall of the confusing lists. This is consistent with the idea that rehearsal and vocalization are sharing a limited articulatory memory resource, not a specific phonetic process.

In reading, concurrent vocalization may play a role similar to its role in memory. That is, it may impair reading, not because it interferes with phonological activation, but because it requires capacity within a limited capacity cognitive system. Waters (Note 4) has investigated this question by equating the effects of verbal and nonverbal secondary tasks on simple nonreading baseline tasks and then comparing their effects on reading. She has demonstrated that concurrent vocalization tasks interfere with reading only insofar as they make additional processing demands. There was no specifically verbal interference in her experiments. Baddeley and Lewis (1981), on the other hand, indicated that counting reduced accuracy on their reading task, while tapping, a nonverbal task, did not. However,

[1] We have recently replicated the tongue-twister effect in both skilled and less skilled fourth-grade readers in an experiment that controlled visual similarity by alternating upper and lower case between words.

as Waters' research demonstrates, it is difficult to compare the specifically verbal interference caused by two very different secondary tasks without assessing their general processing demands.

If, as we suggest, concurrent vocalizing has its effect through increasing resource demands, then the phonological activation of reading should be less vulnerable to resource limitations insofar as it is "automatic" (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). If it is an automatic part of lexical activation, it should show no effect due to concurrent vocalization. This is what our experiments demonstrate.

Others have proposed this distinction between assumedly phonological processes that are vulnerable to suppression by concurrent vocalization and those that are not affected. Similar distinctions have been made by Baddeley and Lewis (1981) and Besner, Davies, and Daniels (1981) from their examinations of the effects of concurrent articulation on homophony and rhyme decisions. Our interpretations do, however, differ from those offered by either, in two important ways: First, that activation of phonological information is an automatic by-product of lexical access, not necessarily a route to lexical access; second, that any observed suppression effects may be due not to interference with specific speech mechanisms, but rather to more general capacity drains, as Waters (Note 4) argues.

Finally, it may be helpful to think of phonological activation as a continuum, with the automatic activation which occurs upon lexical access falling at the low end of the activation continuum and resource-demanding recoding of the sort involved in rehearsal falling at the high end. Concurrent vocalization may be noticeably disruptive only for processes requiring the highest levels of phonological activation, such as rehearsal, since these processes also require cognitive capacity (see Perfetti & McCutchen, in press, for a more detailed discussion). By this capacity interpretation, many of the conflicting results from suppression studies can be attributed to the difficulty of the secondary tasks, not to modality specificity as has been argued (Levy, 1977, 1978). It makes sense, by this capacity interpretation, that Baddeley and Lewis (1981) found that counting form one to six did not interfere with rhyme judgments, while Kleiman (1975) found that a more difficult task such as digit shadowing did produce interference. The capacity interpretation of concurrent vocalization effects entails rejecting vocalization tasks for isolating specific speech processes during reading (see also Waters, Note 4.)

In summary, we have suggested that the visual tongue-twister effect demonstrates that phonological activation occurs in reading sentences and that specific phonemic features are part of what gets activated. Because of the lack of specific interference of concurrent vocalization, we have also suggested that concurrent vocalization has its effect on processing resources but not on automatic phonological activation. This suggestion, which now has evidence (Waters, Note 4), eliminates much of the difficulty in interpreting concurrent vocalization effects that has arisen in the research on speech in reading.

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