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Tongue-Twister Effects in the Silent Reading of Hearing and Deaf College Students

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To investigate whether deaf readers use phonological information during sentence comprehension, deaf and hearing college students performed a semantic acceptability task on tongue-twister and control sentences. Indicative of phonological coding, subjects' responses were influenced by the phonetic content of the sentences they were reading and by the phonetic content of a concurrent memory load task. That is, the subjects in both groups made more errors in their acceptability judgments when reading tongue-twister than when reading control sentences. In addition, subjects in both groups made more errors when the tongue-twister sentences and concurrent memory load numbers were phonetically similar than when they were phonetically dissimilar. These results support theories that assign phonological processes an important role in reading. © 1991 Academic Press, Inc.

The question addressed by the present study is whether deaf readers use a phonological code during reading. Our interest in this question is prompted by the fact that deaf readers provide a strong test case for the importance of phonological processes in reading. These readers lack direct (i.e., auditory) access to the spoken English and, as a result, should have considerable difficulty in acquiring a phonological code. Moreover, deaf readers might use alternatives to phonological coding (e.g., visual or sign coding) if these alternatives were effective. The deaf subjects in the present study were all prelingually, profoundly deaf college students from deaf families, and had learned American Sign Language (ASL) as a first language. A finding of phonological coding[1] by these subjects, because of the degree of their hearing loss and because of their access to coding alternatives, would provide support for theories that place importance on phonological processes in

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[1] The term *phonology* has been used to describe signed languages as well as spoken languages. For example, this term has been used to describe the visible gestures of a signer's hands, face, and body that are the linguistic primitives of ASL (e.g., Liddell & Johnson, 1986; Padden & Perlmutter, 1987). In the present article, however, we use the term *phonology* to refer only to spoken languages.

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reading (see, for example, Huey, 1908/1968; Perfetti, 1985; Shankweiler & Crain, 1986).

We know from short-term memory research that it is possible for prelingually, profoundly deaf individuals to acquire and use a phonological code. For example, in the recall of printed words some deaf college students are sensitive to rhyme, performing more poorly when recalling lists of rhyming than nonrhyming words (Hanson, 1982; Engle, Cantor, & Turner, 1989; Hanson & Lichtenstein, 1990). Moreover, we know that the use of phonological coding in such short-term memory tasks is characteristic of deaf good readers, but not deaf poor readers (Conrad, 1979; Hanson, Liberman, & Shankweiler, 1984; Hanson & Lichtenstein, 1990). Although this short-term memory research may be used to argue that phonological processes underlie skilled reading even in deaf populations, there has been no convincing research that phonological coding actually is used by these individuals during reading.

Previous research directed at this question generally has used proofreading tasks. In proofreading tasks, subjects read passages of text and cancel out all the instances of a particular target letter in the text. Corcoran (1966) found that hearing subjects fail to detect more silent letters (such as the letter e in the word *tape*) than pronounced letters (such as e in the word *red*) in proofreading, and interpreted this finding as evidence of phonological coding during reading. Chen (1976) found no significant difference in the number of silent and pronounced *e*s detected by congenitally deaf subjects, and concluded that these subjects, therefore, were not using phonological coding when reading. Similarly, Locke (1978) found no difference in target letter detections by deaf children when target letters occurred in words as a phonemically modal (e.g., *g* in *rag*) or nonmodal (e.g., *rage*) pronunciation. From this outcome, he also concluded that his deaf subjects were not using phonological coding when reading. It is now known, however, that performance in proofreading tasks is influenced by factors such as target position within a word, word frequency, and letter positional frequency (Frith, 1979; Smith & Groat, 1979). The stimuli of Chen (1976) and Locke (1978) were not controlled for these factors. With position of a target in a word controlled, Dodd (1978) found a difference in target letter detections by deaf children as a function of pronunciation. With word frequency controlled, Quinn (1981) similarly found a difference in target letter detections by deaf children as a function of pronunciation. None of these proofreading studies with deaf subjects has controlled for letter positional frequency in words, however. This orthographic structure variable is known to influence the reading of deaf subjects (Hanson, 1986). Due to such stimulus confoundings, the results from these proofreading studies with deaf subjects are inconclusive.

To avoid such stimulus confoundings, we, instead, used a "tongue-twister" task to examine the question of phonological coding by deaf readers. Hearing readers find it more difficult to read tongue-twister sentences (such as *The tired dentist dozed, but he drilled dutifully*), than syntactically and semantically matched controls (such as *The ill fireman tripped, and he walked unsurely*). For example, silent reading of tongue-twister sentences has been found to take longer than silent reading of the matched controls (Haber & Haber, 1982; see also Ayres, 1984). Similarly, semantic acceptability judgements of tongue-twister sentences have been found to be slower and less accurate than judgments of matched controls (McCutchen, Bell, France, & Perfetti, in press; McCutchen & Perfetti, 1982).

Some investigators have hypothesized that the tongue-twister effect is due to phonetic interference (Haber & Haber, 1982; McCutchen et al., in press; McCutchen & Perfetti, 1982). Other investigators, however, have questioned this interpretation of the tongue-twister effect. It has been suggested that the longer response times to tongue-twister sentences may be due to grapheme repetitions, rather than due to phoneme repetitions (Baddeley & Lewis, 1981). This issue of grapheme repetitions proved problematic in an earlier attempt to use the tongue-twister effect to examine reading by deaf adults. In that study, Treiman and Hirsh-Pasek (1983) found longer response times by deaf subjects when reading tongue-twister sentences than when reading control sentences. Their tongue-twister sentences, however, used repeated graphemes. This confounding of visual and phonetic similarity forced those investigators to regard their results as inconclusive with respect to phonological coding.

A study by McCutchen and Perfetti (1982), however, partially unconfounded visual and phonetic similarity in tongue-twister sentences by examining the tongue-twister effect with mixed-grapheme stimuli. These investigators used both same grapheme tongue-twisters, such as *The talented teenager took the trophy in the tournament*, and mixed-grapheme tongue-twisters, such as *The taxis delivered the tourists directly to the tavern*. In this latter example, the alveolar stop tongue-twister contained word initial phonemes of both /d/ and /t/. McCutchen and Perfetti (1982) found the tongue-twister effect in their study to be as large with the mixed-grapheme tongue-twisters as with same-grapheme tongue-twisters.

These mixed-grapheme stimuli reduced, but did not eliminate, the visual and phonetic confounding inherent in tongue-twister sentences. To eliminate the resulting interpretation ambiguity in a tongue-twister task, McCutchen et al. (in press) looked for specific interference in semantic acceptability judgments as a function of the phonetic content of a concurrent memory load. Hearing subjects judged the semantic acceptability of alveolar fricative tongue-twisters (e.g., *The sparrow snatched the spider swiftly off the ceiling*) and alveolar stop tongue-twisters (e.g., *The taxis delivered the tourists directly to the tavern*). Before the subjects saw the sentences, five numbers appeared on the screen for subjects to memorize. The numbers began with alveolar stops (e.g., 12, 2, 20, 25, 22) or alveolar fricatives (e.g., 17, 6, 65, 16, 77). The subjects rehearsed the numbers, judged whether or not the sentence that followed was semantically acceptable, and then recalled as many numbers as they could.

McCutchen et al. found that rehearsal of alveolar stop and fricative numbers interacted with tongue-twister type. Namely, when the memory load consisted of numbers starting with a fricative, it took longer to respond to fricative sentences. When the memory load consisted of numbers starting with a stop, it took longer to respond to stop sentences. Recall of the numbers showed the same interaction, with more errors when the numbers and the sentences shared initial phonemes. The memory load numbers were visually distinct from each other (e.g., 7, 6, 16, 77) as well as from the sentence graphemes, demonstrating that the interference in this task was not visual. Rather, this interaction between tongue-twister type and memory load type could be clearly attributed to specific interference between the phonetic content of the sentences and the memory load.

The present study uses the procedures of McCutchen et al. (in press) to ascertain whether deaf college students use a phonological code in the silent reading of sentences. A phonological code would be indicated by tongue-twister effects and, more convincingly, by specific interference due to the phonetic content of the concurrent memory load.

Method

Subjects. The deaf subjects were 16 paid volunteers from Gallaudet University. All had deaf parents and were profoundly deaf, with hearing losses of 85 dB or greater, better ear average, as indicated by college records. All reported that ASL was used in the home, and that they considered ASL to be their first language. The data for two of these subjects were eventually dropped due to their performance on the number recall task. One subject produced no correct responses on the number recall task. The other subject failed to write down numbers on some trials. As a result, this subject lost his place on the answer sheet, making his number recall data impossible to score.

Reading scores were available for 11 of the remaining subjects from the comprehension test of *Gates–MacGinitie Reading Tests—Second Edition* (1978, Level F, Form 2). The median reading level for these subjects was grade 8.7 (range = 12.9+ to 3.3). Given that the average reading level of profoundly deaf high school graduates is approximately third grade (Conrad, 1979; Karchmer, Milone, & Wolk, 1979), most of these subjects were quite good deaf readers. Speech intelligibility scores were provided by Gallaudet University for those 12 students who had been tested by the Audiology Department at the University. The scores are based on a scale from 1 to 5, in which "1" is easily intelligible and "5" is unintelligible. For these subjects, one had speech rated a "2," another one had speech rated a "3.5," five had speech rated a "4," and five had speech rated a "5." On the whole, therefore, the speech of these subjects was not very intelligible.

The hearing subjects were 16 undergraduate students at the University of Connecticut who participated in the experiment to fulfill a course requirement.

Stimulus materials. The stimuli were the 144 alveolar stop, alveolar fricative, and control sentences previously used by McCutchen et al. (in press). These stimuli consisted of three sets of 48 syntactically matched sentences, differing in the initial consonants of the content words. The tongue-twister stimuli included both same-grapheme tongue-twisters and mixed-grapheme tongue-twisters. The content words in the alveolar stop sentences began with either /t/ or /d/, while the content words in the fricative sentence with either /s/ or /z/. The content words in the control sentences contained a mix of initial phonemes that excluded the two stop and fricative phonemes used in the experimental sentences.

McCutchen et al. constructed the semantically unacceptable sentences so that content words were rearranged within each sentence type. This allowed syntactic structure to remain unchanged. Half of the stimuli were semantically acceptable sentences, while the other half were semantically unacceptable. To ensure that the tongue-twister sentences were not more bizarre than the control sentences, McCutchen et al. (in press) asked hearing undergraduates to rate the semantic acceptability of all sentences designated as semantically acceptable. Results indicated that the tongue-twister sentences were no more or less bizarre than the control sentences. See McCutchen et al. (in press) for further details on stimulus selection. Examples of semantically acceptable and unacceptable sentences for fricative, stop, and control sentences are as follows:

Fricative sentences

Acceptable: The spacious zoo sits beside a sandy seashore.

Unacceptable: The salty zone smashed beside the skillful station.

Stop sentences

Acceptable. The tiny toddler dreamed of her toy tiger.

Unacceptable: The damaged detective dreamed in the tattered toddler.

Control sentences

Acceptable. The amusement park was beside a rocky beach.

Unacceptable: A black bush knew beside the walking stories.

Two test lists were created. These lists differed in terms of which sentences were presented in the memory load condition: the sentences tested in the memory load condition in one list were tested in the no memory load condition in the other, with the order in which the sentences appeared differing in the two lists. Equal numbers of each sentence type were included in each test list. The memory load condition preceded the no memory load condition on both lists.

There were two sets of numbers for the number recall task. In one set, the names for the numbers began with the alveolar stop /t/ (e.g., 2, 12, 22, 23, 24, 25, 28, 29) while in the second the names began with the alveolar fricative /s/ (e.g., 6, 7, 16, 17, 66, 63, 65, 68, 74, 79). A subset of five numbers was randomly picked for use on each recall trial.

Procedure. The subjects were individually tested. For the deaf subjects, the experimenter was a deaf native signer of ASL who was a former Gallaudet University student. For the hearing subjects, the experimenter was a graduate student at the University of Connecticut.

To familiarize themselves with the recall task, subjects began a testing session with four practice trials on which only the number recall task was given. These numbers were random, beginning not necessarily with either stops or fricatives. In this phase, subjects were instructed that their task was simply to recall a set of numbers briefly shown on a computer screen. They were to write this set of numbers in the spaces provided on their answer sheets when the numbers disappeared from the computer screen. The numbers appeared for 5 s, then disappeared.

Following completion of the number recall practice, the experimental session began. This session consisted of four practice trials, followed by testing with one of the two stimulus lists. Half of the subjects in each group saw each test list. The subjects were given a brief rest after every 24 test trials.

For testing with a memory load, subjects were instructed that they were to read each sentence, decide whether it made sense, indicate their decision by pressing a telegraph key, and then write the numbers. They were asked to sit with their index fingers resting one on each of two labelled telegraph keys, and indicate their decisions about semantic acceptability by pressing one of these two keys as quickly and as accurately as possible. The right-hand key was used to indicate semantically acceptable sentences.

The start of a trial was signalled by the appearance of five numbers at the center of the screen. After a blank interval of 250 ms, the sentence was then presented in the center of the screen, wrapped to a second line when too long to fit on one line. The sentence remained in view either until the subject pressed a response key or until 5 s had elapsed. The subjects were informed that feedback would be given on each trial. The feedback was the subject's RT (in ms) for his/her acceptability judgment. If the subject had failed to respond within the 5 s time limit, the words TOO SLOW appeared as feedback. (To anticipate, however, there were no cases in which a subject failed to respond during the time limit on test trials.) The feedback, displayed for 250 ms, was centered six lines below the sentence.

If subjects asked how to know if a sentence "made sense," they were told to decide based on whether the meaning of the sentence was bizarre. They were informed that the spelling and syntax of sentences would always be correct, so that they need not look for spelling or grammatical errors.

At the end of the 72 experimental trials with the memory load, the answer sheets for number recall were collected and the subjects then performed 72 trials without the memory load. The procedure for the trials without a memory load was identical, except that no number string was presented before the test sentences and no number recall was required. No practice trials were given for this condition. The instructions for these trials without a memory load were given following the trials with a memory load. These instructions informed the subjects that they were simply to continue to decide whether the sentence made sense and that they no longer needed to recall numbers. As in the memory load condition, the subjects were given a brief rest after every 24 trials.

Results

The data for semantic acceptability judgments and number recall were analyzed to determine if performance on tongue-twister sentences differed from that on control sentences, and to determine whether there was any specific interference in sentence reading or number recall as a function of the phonetic content of the concurrent memory load. For the semantic acceptability judgments, median response times (RTs) for correct trials and mean percentage errors were analyzed. For number recall, subjects' mean percentage of errors in recalling the memory load numbers was analyzed. As in the study of McCutchen et al. (in press), the number recall data were scored irrespective of order. Unless otherwise specified, only effects that reached statistical significance in both the subjects and the items analyses are reported.

Tongue-Twister Effects

ANOVAs were performed on the semantic acceptability judgment data for the factors of sentence type (tongue-twister sentences, control sentences), memory load (no memory load, memory load), acceptability (acceptable, unacceptable), and group (hearing, deaf). These analyses revealed significant tongue-twister effects in the error data [$F(1,28) = 14.40$, $MS_e = 73.60$, $p < .001$, for subjects; $F(1,140) = 4.78$, $MS_e = 456.40$, $p < .05$, for items]. Table 1 gives the mean errors and RTs for hearing and deaf subjects in this task, showing that subjects made more errors on tongue-twister (20.6% errors) sentences than on control sentences (16.3% errors).

The analyses of the semantic acceptability data further revealed that the deaf subjects were faster [$F(1,28) = 4.65$, $MS_e = 1937163.20$, $p < .05$, for subjects; $F(1,139) = 368.05$, $MS_e = 118497.59$, $p < .001$, for

TABLE 1

Mean Correct Response Times (RTs) and Mean Percentage Errors for Acceptability Judgments in the No Memory Load and Memory Load Conditions on Tongue-Twister and Control Sentences

	No memory load			
	RTs		Errors	
	Hearing	Deaf	Hearing	Deaf
Acceptable sentences				
Tongue-twister	2897 (654)	2587 (547)	14.0 (11.3)	22.8 (9.9)
Control	2698 (505)	2454 (561)	5.1 (7.3)	16.5 (9.2)
Unacceptable sentences				
Tongue-twister	2899 (542)	2568 (549)	12.7 (13.5)	26.5 (16.7)
Control	2859 (661)	2543 (531)	9.3 (12.5)	28.0 (22.1)
	Memory load			
Acceptable sentences				
Tongue-twister	3158 (535)	2632 (619)	20.6 (13.5)	24.0 (6.0)
Control	2999 (410)	2471 (639)	15.2 (13.9)	14.6 (10.0)
Unacceptable sentences				
Tongue-twister	3169 (411)	2708 (547)	17.1 (12.6)	29.0 (17.0)
Control	3047 (611)	2656 (753)	14.8 (20.9)	29.6 (16.9)

Note. Standard deviations are shown in parentheses.

items], although less accurate [$F(1,28) = 12.02$, $MS_e = 524.09$, $p < .005$, for subjects; $F(1,140) = 14.24$, $MS_e = 262.40$, $p < .001$, for items] than the hearing subjects. The mean RT for the group of deaf subjects was 2578 ms, with 23.9% errors overall, as compared with a mean RT of 2966 for the group of hearing subjects, with 13.6% errors overall. In the RT analysis there was a main effect of acceptability, [$F(1,28) = 5,78$, $MS_e = 49343.45$, $p < .05$, for subjects; $F(1,139) = 4.73$, $MS_e = 160773.72$, $p < .05$, for items], reflecting faster RTs on semantically acceptable than unacceptable sentences.

For the number recall error data summarized in Table 2, ANOVAs were performed on the factors of sentence type (tongue-twister, control), acceptability (acceptable, unacceptable), and group (hearing, deaf). Only the main effect of group. [$F(1,28) = 30.82$, $MS_e = 457.77$, $p < .001$, for subjects; $F(1,140) = 339.33$, $MS_e = 86.98$, $p < .001$, for items], and the interaction of acceptability X group, [$F(1,28) = 14.73$, $MS_e = 21.36$, $p < .001$, for subjects; $F(1,140) = 7.90$, $MS_e = 86.98$, $p < .01$, for items], reached statistical significance in both subjects and items analyses. The main effect of group reflected more errors by the deaf subjects than by the hearing subjects. The interaction indicated that while the deaf subjects made somewhat more errors on tongue-twister than control sentences whether semantically acceptable or unacceptable, the hearing subjects made considerably more errors on the tongue-twisters when the sentences were unacceptable than when they were acceptable.

TABLE 2

Mean Percentage Errors in Recalling Numbers of the Concurrent Memory Load on Tongue-Twister and Control Sentences

	Hearing	Deaf
Acceptable sentences		
Tongue-twister	31.0 (12.1)	56.2 (10.2)
Control	30.3 (11.1)	55.1 (11.6)
Unacceptable sentences		
Tongue-twister	36.3 (10.3)	54.1 (9.6)
Control	32.5 (14.5)	51.6 (10.9)

Note. The standard deviations are shown in parentheses.

Specific Interference

To test for specific interference due to memory load, the acceptability judgement data and the number recall data of the Memory Load Condition were analyzed in terms of the factors of tongue-twister type (fricative, stop), memory load type (fricative, stop), acceptability, and group.

In the analyses of the acceptability judgments, specific interference effects were obtained in the error data. As shown in Table 3, the interaction of tongue-twister type *X* memory load type [$F(1,28) = 37.91$, $MS_e = 115.46$, $p < .001$, for subjects; $F(1,92) = 8.79$, $MS_e = 365.14$, $p < .005$, for items] reflected specific interference of the memory load. With fricative numbers as the memory load, there were more errors on acceptability judgments for fricative sentences (27.0%) than for stop sentences (18.9%), $t(29) = 3.50$, $p < .005$, two-tailed. Conversely, with stop numbers as the memory load there were more errors on acceptability judgments for stop sentences (25.6%) than for fricative sentences (17.0%), $t(29) = 3.38$, $p < .005$, two-tailed. Important for indicating phonological coding for deaf subjects, the specific interference interaction was present in the data of the deaf subjects alone [$F(1,13) = 39.17$, $MS_e = 100.18$, $p < .001$, for subjects; $F(1,92) = 7.90$, $MS_e = 384.35$, $p < .01$, for items]. The comparable analysis of the hearing subjects' data reached significance only in the subjects analysis, [$F(1,15) = 6.94$, $MS_e = 128.69$, $p < .02$, for subjects; $F(1,92) = 2.66$, $MS_e = 235.11$, $p < .11$, for items].

As in the tongue-twister analyses, the specific interference analyses of the semantic acceptability judgments revealed that

TABLE 3

MEAN CORRECT RESPONSE TIMES (RTs) AND MEAN PERCENTAGE ERRORS FOR ACCEPTABILITY JUDGMENTS IN THE MEMORY LOAD CONDITION AS A FUNCTION OF TONGUE-TWISTER TYPE (FRICATIVE, STOP) AND MEMORY LOAD TYPE (FRICATIVE, STOP)

	Fricative memory load			
	RTs		Errors	
	Hearing	Deaf	Hearing	Deaf
Acceptable sentences				
Fricative	3205 (651)	2512 (672)	26.1 (18.1)	29.7 (16.1)
Stop	3222 (525)	2537 (590)	19.7 (23.6)	16.7 (12.9)
Unacceptable sentences				
Fricative	3056 (540)	2484 (502)	16.8 (19.2)	36.9 (23.8)
Stop	2997 (491)	2726 (547)	17.7 (15.3)	21.5 (20.0)
	Stop memory load			
Acceptable sentences				
Fricative	3076 (614)	2727 (817)	13.6 (12.4)	14.4 (14.4)
Stop	3129 (630)	2755 (631)	21.9 (24.9)	34.5 (17.8)
Unacceptable sentences				
Fricative	3238 (608)	2769 (697)	12.5 (17.7)	28.5 (15.0)
Stop	3388 (389)	2854 (816)	19.9 (16.3)	27.4 (17.9)

Note. Standard deviations are shown in parentheses.

the deaf subjects were faster, [$F(1,28) = 6.98$, $MS_e = 2083185.68$, $p < .05$, for subjects; $F(1,88) = 62.39$, $MS_e = 245496.05$, $p < .001$, for items], although less accurate [$F(1,28) = 5.37$, $MS_e = 657.66$, $p < .05$, for subjects; $F(1,92) = 8.26$, $MS_e = 254.32$, $p < .01$, for items] than the hearing subjects.

In the ANOVAs on the percentage of errors in number recall, no specific interference effects emerged. The only effects involving memory load type to reach statistical significance were the main effect of this variable [$F(1,28) = 62.48$, $MS_e = 209.47$, $p < .001$, for subjects; $F(1,88) = 160.24$, $MS_e = 77.63$, $p < .001$, for items], and a two-way interaction of memory load type X group [$F(1,28) = 12.12$ $MS_e = 209.07$, $p < .002$, for subjects; $F(1,88) = 32.65$, $MS_e = 62.23$, $p < .001$, for items]. As shown in Table 4, the main effect of memory load type was reflective of fewer recall errors when the memory load was stop numbers than when it was fricative numbers. The interaction of memory load type X group indicated that while the deaf subjects had roughly comparable accuracy in recall for fricative and stop numbers the hearing sub-

TABLE 4

MEAN PERCENTAGE ERRORS IN RECALLING THE NUMBERS OF THE CONCURRENT MEMORY LOAD

	Fricative memory load		Stop memory load	
	Hearing	Deaf	Hearing	Deaf
Acceptable sentences				
Fricative	41.4 (18.1)	65.0 (11.0)	17.7 (10.7)	45.9 (14.2)
Stop	41.6 (17.2)	59.7 (14.3)	23.5 (14.0)	54.2 (12.0)
Unacceptable sentences				
Fricative	46.0 (13.1)	58.8 (12.5)	23.3 (13.9)	50.9 (12.4)
Stop	48.3 (11.6)	53.8 (14.7)	27.7 (20.1)	53.0 (17.2)

jects had much better recall for fricative than stop numbers.

As in tongue-twister analyses of the number recall data, the deaf subjects were less accurate than the hearing subjects [$F(1,28) = 31.95$, $MS_e = 862.91$, $p < .001$, for subjects; $F(1,88) = 365.39$, $MS_e = 62.23$, $p < .001$, for items]. The analysis of number recall also indicated an interaction of group X acceptability, [$F(1,28) = 16.48$, $MS_e = 48.85$, $p < .001$, for subjects; $F(1,88) = 5.60$, $MS_e = 62.23$, $p < .05$, for items], with the deaf subjects making roughly the same percentage of errors on both acceptable and unacceptable sentences, and the hearing subjects making nearly twice as many errors on acceptable than unacceptable tongue-twisters.

Discussion

The present study used a semantic acceptability task to examine whether deaf college students use phonological coding during reading. Indicative of phonological coding, subjects' semantic acceptability judgments showed both tongue-twister and specific phonetic interference effects.

Both the hearing and the deaf college students in this study made more errors on acceptability judgments when reading tongue-twister sentences than when reading control sentences. This outcome replicates the tongue-twisters effect from earlier work with hearing subjects, showing that tongue-twister sentences are more difficult to read than sentences that do not have this phonetic loading (Haber & Haber, 1982; McCutchen & Perfetti, 1982; McCutchen et al., in press). As noted previously, however, tongue-twister effects are often viewed skeptically due to their inherent confounding of visual and phonetic similarity. Even in studies, such as the present one, that attempt to reduce this confounding by using mixed-grapheme tongue-twisters, this confounding is not eliminated.

More conclusive evidence of phonological involvement in the present study was the specific phonetic interference. The error data for acceptability judgments showed more errors when the tongue-twister sentences and the concurrent memory load numbers were phonetically similar. Both the hearing and the deaf subjects had difficulty making acceptability judgments about fricative sentences when the memory load consisted of fricative numbers. Conversely, both groups had difficulty in making acceptability judgments about stop sentences when the memory load consisted of stop numbers. This outcome confirms the earlier finding of specific phonetic interference reported by McCutchen et al. (in press) for hearing college students, and extends the finding to deaf college students. Since the written forms of the sentences and numbers do not overlap visually, this result cannot be attributed to graphemic similarity. Rather, the interference would seem attributable to the phonetic similarity of the sentences and numbers.

There were no significant interactions involving subject group related to the tongue-twister effect or the specific interference effect. We note, however, a speed-accuracy trade-off in the semantic acceptability judgment data, with the deaf subjects being faster and less accurate than the hearing subjects in their responding.

There was no evidence of either tongue-twister or specific interference in the number recall data. As noted earlier by McCutchen et al. (in press), there seem to be processing trade-offs in this task, such that the tongue-twister and specific interference effects may appear either in the acceptability judgment data or the number recall data. In the present study, these effects were apparent only in the acceptability judgments data. The number recall data showed only that the hearing subjects recalled more numbers than the deaf subjects, and that the hearing subjects were more influenced by the semantic acceptability of the sentences than were the deaf subjects.

The present results argue that a phonological code is indeed used in sentence comprehension during reading—by both hearing and deaf subjects. What role would it have? Most likely a phonological code is useful in maintaining words in working memory to allow for the processing of individual words and to assemble the words into phrases and sentences (Baddeley & Hitch, 1974; Huey, 1908/1968; Perfetti, 1985; Shankweiler & Crain, 1986). Research with deaf subjects has suggested that this code may be particularly useful for retaining words in their correct sequential order (Hanson, 1990; Lake, 1980) and for retention and interpretation of free morphemes and articles (Taeschner, Devescovi, & Volterra, 1988; Volterra & Bates, 1989).

A phonological code may not be the only code that can be used to mediate sentence comprehension during reading, however. For example, Treiman and Hirsh-Pasek (1983), testing deaf subjects who were less proficient readers than those of the present study, found that their subjects had more difficulty reading "finger-fumbler" (Klima & Bellugi, 1979) than control sentences. These finger-fumbler sentences had words whose corresponding signs were formationally similar. Those subjects, therefore, may have been using a sign code to mediate comprehension. It is noteworthy that the best deaf readers in Treiman and Hirsh-Pasek's (1983) study did not show finger-fumbler effects.

Strikingly, the deaf subjects of the present study all had deaf parents and reported ASL to be their first language. Despite this access to an alternative, these subjects used phonological coding in the present reading comprehension task. Also of interest is the fact that the deaf subjects of the present study did not tend to have outstanding speech production skills, as judged by listeners. Yet, again, even these subjects were found to use phonological coding. Importantly, these deaf subjects, as a group, had reading scores that were exceptionally high for deaf readers. It is possible, indeed likely, that we would not find evidence of phonological coding if a group of deaf poor readers were tested in this tongue-twister task. Such a finding would be consistent with short-term memory research, which has generally found the use of phonological coding to be limited to those deaf subjects who are the better readers (Conrad, 1979; Hanson & Lichtenstein, 1990).

Although a phonological code is often characterized as acoustic or auditory, our results suggest that these characterizations may be incomplete and, in the case of profoundly deaf persons, inaccurate. Although access to auditory information may enhance the effectiveness of a phonological code (Hanson, in press), research with deaf subjects suggests that descriptions of a phonological code should not be limited to being auditory in nature. Our results are consistent, for example, with the possibility that a phonological code for deaf readers could be *visually* derived, based on the look of words on the lips of speakers (see, also, Dodd & Hermelin, 1977). Indeed, the possibility that hearing persons also have a visual component to their phonological code is consistent with studies of lipreading and the "McGurk effect." In studies of lipreading, hearing subjects generally lipread as well as or better than deaf subjects trained in lipreading (Conrad, 1977; Pelson & Prather, 1974). The "McGurk effect" shows that in identifying certain phonemes, hearing subjects may report the phoneme they see on the lips of the speaker rather than the phonemes that they actually hear when the two sources of input conflict (MacDonald & McGurk, 1978; McGurk and MacDonald, 1976). Both the lipreading results and the "McGurk effect" indicate that hearing subjects, despite never having received explicit training in lipreading, know a great deal about the visual correlates of phonemes.

In summary, the tongue-twister and specific interference effects reported here provide evidence for the use of phonological code in the silent reading of deaf college students. Given these subjects' access to coding alternatives and their difficulty in acquiring a phonological code, the present results provide strong support for theories that assign phonological processing an important role in reading.

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