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Effects of Irrelevant Sounds on Phonological Coding in Reading Comprehension and Short-term Memory

Robyn Boyle and Veronika Coltheart
Macquarie University, Sydney, Australia

The effects of irrelevant sounds on reading comprehension and short-term memory were studied in two experiments. In Experiment 1, adults judged the acceptability of written sentences during irrelevent speech, accompanied and unaccompanied singing, instrumental music, and in silence. Sentences varied in syntactic complexity: Simple sentences contained a right-branching relative clause (*The applause pleased the woman that gave the speech*) and syntactically complex sentences included a centre-embedded relative clause (*The hay that the farmer stored fed the hungry animals*). Unacceptable sentences either sounded acceptable (*The dog chased the cat that eight up all his food*) or did not (*The man praised the child that sight up his spinach*). Decision accuracy was impaired by syntactic complexity but not by irrelevant sounds. Phonological coding was indicated by increased errors on unacceptable sentences that sounded correct. These error rates were unaffected by irrelevant sounds. Experiment 2 examined effects of irrelevant sounds on ordered recall of phonologically similar and dissimilar word lists. Phonological similarity impaired recall. Irrelevant speech reduced recall but did not interact with phonological similarity. The results of these experiments question assumptions about the relationship between speech input and phonological coding in reading and the short-term store.

The possible role of phonological codes in reading comprehension has been the subject of investigation for many years. Despite considerable evidence for the utilization of phonological codes in short-term memory, the question as to whether these codes are an essential component of skilled reading remains unanswered. Evidence for the activation of phonological codes in reading comprehension has been established by word and sentence reading tasks using homophones (these studies are discussed later). However

Requests for reprints should be addressed to V. Coltheart, Psychology Department, School of Behavioural Sciences, Macquarie University, NSW 2109, Australia. Email: bh_coltheart@hope.ocs.mq.edu.au

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the function these codes serve in reading comprehension is by no means clear: They may simply be a by-product of automatic processing, or they may reflect the involvement of short-term memory. Various suggestions as to possible roles short-term memory may play in written sentence comprehension have been proposed. These include the function of maintaining a verbatim record for subsequent backtracking (e.g. Baddeley & Lewis, 1981; Besner & Davelaar, 1982), or of keeping surface information available while the sentence is parsed (Hanson, Goodall, & Perfetti, 1991). An alternative view is that a phonological record may be available for assistance during between-sentence integration of concepts and information in text (Coltheart, Avons, & Trollope, 1990; Slowiaczek & Clifton, 1980). The view that parsing and syntactic analyses may be assisted by the maintenance of a phonological record of the words of a sentence was put forward both by psycholinguists and by neuropsychologists who studied patients with short-term memory and sentence comprehension deficits (Caramazza, Berndt, & Basili, 1983; Clark & Clark, 1977; Vallar & Baddeley, 1984). More recently, however, the notion that syntactic analyses in sentence comprehension make demands on short-term working memory has been disputed (Martin, 1993; Waters, Caplan, & Hildebrandt, 1987; Vallar & Shallice, 1990). Much recent research on sentence comprehension indicates that syntactic and semantic information is processed on-line as each word is encountered (see Rayner, Sereno, Morris, Schmauder, & Clifton, 1989, and Marslen-Wilson, Tyler, Warren, Grenier, & Lee, 1992, for a discussion). It has been suggested that the involvement of short-term working memory is restricted to the comprehension of long and complex sentences (Baddeley, 1986) and that a phonological code and the articulatory (phonological) loop system of short-term working memory is used at a late stage of sentence processing when the output of syntactic and semantic analyses is compared to pragmatic and real world knowledge (Waters et al., 1987). If short-term memory is an integral component of reading comprehension, it might be expected that tasks known to interfere with short-term memory will exert similar interference effects on the comprehension process. The contribution of short-term memory has been studied using a memory load, concurrent articulation, and irrelevant (heard) speech. Both a memory load and concurrent articulation have been found to impair the comprehension of longer sentences (Baddeley, 1986; Baddeley, Eldridge, & Lewis, 1981; Waters et al., 1987). The effects of irrelevant speech on sentence comprehension, however, have not been conclusively established. Irrelevant speech is known to impair serial short-term list recall (Colle & Welsh, 1976; Salamé & Baddeley, 1987, 1989), regardless of the meaningfulness of the speech or the intensity at which it is presented (Baddeley & Salamé, 1986; Colle, 1980; Jones, Miles, & Page, 1990). Furthermore, not all irrelevant auditory material interferes with serial short-term recall: white noise, pink noise, auditory tones, and humming do not interfere to the same extent as does verbal material, if at all (Jones, 1993; Morris, Jones, & Quayle, 1989; Salamé & Baddeley, 1982). It has therefore been argued that auditory verbal material (e.g. speech, singing) gains obligatory access to a phonological short-term store and interferes with the storage of list items input by the rehearsal process (Baddeley, 1986, 1992; Baddeley, Lewis, & Vallar, 1984). According to the working memory model of Baddeley and Hitch (1974; Baddeley, 1986), visually presented verbal material is recoded into a phonological form and stored in a phonological short-term store within working memory. Items within the store are refreshed by subvocal rehearsal utilizing the articulatory (phonological) loop. Interference by irrelevant auditory material observed in short-term memory tasks occurs because the auditory material automatically enters the phonological short-term store and corrupts or replaces items currently held there (Baddeley, 1990; Salamé & Baddeley, 1986). If this phonological component of short-term working memory is involved in reading comprehension, then irrelevant speech might be expected to interfere with the comprehension process.

Few studies have directly examined the effects of irrelevant sounds on reading comprehension, although interest in the interference of auditory material with reading extends back to 1945, when Henderson, Crews, and Barlow assessed the effects of popular and classical music on reading, with the aim of determining whether studying with the radio on distracted students from their work. They found that popular music reduced paragraph comprehension, but classical music did not. However, they did not consider the fact that in addition to differing in musical genre, the popular music was vocal, whereas the classical music was entirely instrumental. More recently, Martin, Wogalter, and Forlano (1988) assessed memory for factual material from text passages read in the presence of irrelevant speech and various other ongoing sounds. Although any verbal material, whether spoken or sung, produced adverse effects on recall, greater effects occurred for speech in the listener's own language than for speech in a foreign or unfamiliar language. Martin et al. concluded that the irrelevant speech interfered with *semantic* coding rather than *phonological* coding. However, their memory tests were presented after a filled delay so as to minimize the contribution of short-term working memory. Consequently, the task reflects the functioning of (long-term) episodic memory, rather than short-term working memory.

Jones et al. (1990) examined the effects of various irrelevant sound conditions on a proofreading task. They found that speech disrupted accuracy in detecting certain sorts of typographical errors and not others. Specifically, speech impaired the detection of superficial features of the text: letter omissions and misspellings. Detection of contextual errors requiring comprehension (e.g. inappropriate words and grammatical errors) was unaffected by irrelevant speech. A limit on the conclusions that can be drawn is that no tests of comprehension followed the proofreading task, and it is possible that subjects were simply skimming the text.

Because of the reading paradigms used, neither of these previous studies indicates whether phonological coding serves a function during reading comprehension or whether irrelevant speech affects the formation and/or use of this code. Evidence for the operation of phonological codes during reading comprehension has existed since Baron's (1973) research on phrase evaluation. Subsequent research using longer sentences containing inappropriate homophones has shown that skilled readers derive phonological codes during reading, and that these codes cause errors in sentence evaluation (Coltheart, Laxon, Rickard, & Elton, 1988; Treiman, Freyd, & Baron, 1983). In these experiments, sentences containing a homophone, such as *The none was in church today*, are erroneously judged as acceptable more often than sentences containing an orthographic control word, such as *The nine was in church today*. This phonological effect on error rate is removed by concurrent articulation (Coltheart et al., 1990). Thus, phonological codes are activated during the reading of quite simple sentences. If such codes are required during the analysis of more complex forms of syntactic structure, the phonological effects should be even greater when difficult sentence structures are presented.

EXPERIMENT 1

Experiment 1 investigated phonological coding during the reading of a more complex form of sentence structure that adults find relatively difficult to comprehend. The complex sentence structure contained a centre-embedded relative clause (e.g. *The meat that the butcher cut delighted the customer*) and it was contrasted with a simpler structure containing a right-branching relative clause (e.g. *The man hit the landlord that requested the money*). Increased error rates and RTs have been found for centre-embedded sentences presented to adults, children, and aphasic patients (Caplan, Baker, & Dehaut, 1985; Cook, 1975; Waters et al., 1987). Acceptable and unacceptable sentences of these two types were presented in a sentence evaluation task in which skilled readers made speeded judgements as to whether each sentence was acceptable English, with no grammatical, spelling, or other errors. The simple and complex unacceptable sentences were of two types: phonologically plausible (containing a homophone) or phonologically implausible (containing an orthographic control word). Noun animacy was controlled and balanced across both acceptable and unacceptable sentence types, as animate nouns are typically more readily assumed to be agents than are inanimate nouns (Comrie, 1981).

The effects of irrelevant sounds on reading comprehension were also studied. In most previous research on the effects of irrelevant sounds, the differences between different classes of sound have not been systematically controlled. When instrumental and vocal music have been contrasted, these have differed in musical style, number and type of instruments used, and in many other features. Contrasts between speech and singing have been based on spoken prose and accompanied songs differing greatly in content. There are many possible differences between accompanied forms of song: for example, whether one or more instruments accompany the singer can greatly affect the intelligibility of the words sung because of the masking generated by different types and differing numbers of accompanying instruments. Consequently, the irrelevant sounds in Experiment 1 were constructed to vary more systematically. Five types of sound conditions were constructed: speech, unaccompanied singing, accompanied singing, instrumental music, and silence. The same material was used in the spoken and various musical versions and consisted of Gilbert and Sullivan "patter" songs, chosen for their uniformity of musical characteristics. Patter songs attempt to mimic the continuous flowing rhythm of normal speech, do not use the exaggerated vowel sounds found in other songs containing long sustained notes, and do not have large leaps in pitch. Thus, they resemble speech more than do most other songs. These songs were also sufficiently long to enable presentation of sound segments that were not repeatedly played over and over, thus lessening the likelihood of habituation (Morris & Jones, 1990a). Use of this material also made it possible to construct vocal and instrumental versions of four different patter songs spoken or sung by the same performer, with accompaniments played by the same musician. This both enabled presentation of a given song in only one version to each subject and increased the generality of the findings, which were thereby not confined to a single song.

The sentences were presented along with each of the four sound conditions described above and also in silence. The experiment used a repeated-measures design with the order of sound conditions and sentence set counterbalanced across subjects. It was predicted that if irrelevant speech sounds (phonemes) have obligatory access to a phonological store used in sentence comprehension, then the vocal sound conditions would disrupt sentence evaluation more than would the instrumental and silent conditions. If reliance on a phonological code depends on syntactic complexity, then the adverse effects of vocal sounds might be increased for complex sentences when compared to simple sentences. Finally, if reliance on phonological coding is more likely for syntactically complex sentences, then errors to complex unacceptable homophone sentences can be predicted to exceed those to their simple counterparts. A reduction of these phonological effects by vocal sound conditions might be expected if irrelevant speech is assumed to inhibit phonological coding.

Method

Subjects

Forty first-year behavioural sciences students from Macquarie University participated in the study for course credit. Subjects ranged in age from 18 to 54; all reported normal hearing and normal or corrected-to-normal vision and were native English speakers.

Stimulus Materials and Conditions

Sound Backgrounds. The background sound conditions consisted of a silent control condition and four sound conditions: (1) instrumental music, (2) singing with instrumental accompaniment, (3) unaccompanied singing, and (4) speech. Four Gilbert and Sullivan "patter" songs were chosen for the sound conditions because of their uniformity in terms of musical style, pitch range, melodic contours, and rhythmic patterns. Each of these songs was recorded in each of the above conditions, creating four versions of each song: an instrumental version, a sung version with instrumental accompaniment, a sung version without accompaniment, and a spoken version. Each song was edited onto a tape three times to produce a continuous recording lasting approximately 9 min. This was done in order to ensure that sounds did not cease before the end of sentence presentation for any unusually slow subjects.

A trained baritone and musical comedy performer sang and spoke the songs for the recordings. The spoken versions of the songs were uttered in a continuous manner at the same speed as the musical versions. The rate of utterance was paced by a metronome running at 132 beats per minute, with two to three syllables per beat—approximating a normal rate for conversational speech (and slower than the 184–200 beats per minute at which these songs would normally be performed). This ensured uniformity of speeds across the four songs and across the four versions of each song. The spoken version of each song had the same rhythm and pauses as the sung versions. The instrumental version was produced by a synthesized clarinet playing the melody of the songs at the same pitch as that of the vocal conditions, with piano accompaniment. The same piano accompaniment was used for the accompanied singing condition.

Sound backgrounds were played on a Marantz SuperScope tape recorder (model C–207–LP) and presented through Sansui (Type SS2) stereo headphones at an average level of 75dB(A). This is quite loud, distracting, and difficult to ignore. The ambient level for the silent condition was 37dB(A).

Sentence Reading Task. The stimuli consisted of 160 acceptable and 160 unacceptable sentences differing in syntactic complexity.[1] Half the sentences of each type contained an animate subject (e.g. *man*, *girl*, *dog*), and half contained an inanimate subject (e.g. *table*, *book*, *house*). All sentences contained one of two types of relative clause. The syntactically simple sentences had a right-branching relative clause modifying the object noun phrase of the main clause (e.g. *The applause pleased the woman that gave the speech*). The syntactically complex sentences contained a centre-embedded relative clause in which the relative clause modifies the subject noun phrase and precedes the main clause verb (e.g. *The hay that the farmer stored fed the hungry animals*) (Waters et al., 1987).

A set of 160 unacceptable sentences was formed by replacing a word with an inappropriate homophone or with an orthographically similar control word. Unacceptable homophone sentences were phonologically plausible, whereas unacceptable control sentences were phonologically implausible. All unacceptable sentences were syntactically and/or semantically anomalous[2] and had been judged so by pilot subjects. Half of the sentences were syntactically simple and half were complex as described above. Some examples of the four sentence types follow:

1. *The mother taut the child that played the clarinet* (simple with homophone);
2. *The teacher tight the class that painted the poster* (simple with orthographic control word);
3. *The truck that the boys watched toad away the crane* (complex with homophone);
4. *The van that the police drove toned away the parked car* (complex with orthographic control word).

Two versions of the unacceptable sentences were constructed such that in Set 1, Sentences 1 and 3 contained the homophone substitutions, and in Set 2, Sentences 2 and 4 had the homophone substitutions, and Sentences 1 and 3 had the orthographic control words.

The 80 homophones and their orthographic controls were matched on mean log word frequency: 1.16 for homophones and 1.06 for controls in simple sentences; 1.01 for homophones and 1.12 for controls in complex sentences (Johansson & Hofland, 1989) and on mean graphic similarity: 605, 605, 647, and 646, respectively (Weber, 1970). The words are listed in the Appendix. The anomalous homophone or control word occurred equally often at the beginning, middle, or end of a sentence. Sentences ranged in length from 50–60 characters (9 to 11 words), with a mean length of 55 characters.

Procedure

Each subject was tested individually in a quiet room. Sentences were presented one at a time on a Macintosh computer using the Psychlab programme (Gum & Bub, 1985). Subjects were instructed to read each sentence silently and to decide whether it made sense and was an acceptable English sentence. Subjects were instructed to respond as quickly and accurately as possible by pressing the "/" or "Z" keys, labelled "Yes" and "No", respectively. Responses erased the sentence from the

[1] We thank Gloria Waters who kindly provided us with the sentences used by Waters et al. (1987). Approximately a third of the acceptable sentences were taken from their set, and the remainder were devised by one of us, as were the unacceptable sentences, which required inappropriate homophones and orthographic control words.

[2] Approximately half the unacceptable sentences containing homophones and those containing orthographic control words were both syntactically and semantically anomalous; the remainder preserved syntactic acceptability and were merely semantically inappropriate.

screen and initiated the next sentence after a constant interval of 1500 msec. Prior to the experiment, subjects were given 16 practice trials in silence, consisting of sentences identical in syntactic structure to the experimental trials.

Background sounds were presented over a set of headphones that subjects wore throughout the experiment. They were instructed to try to ignore the background sounds and to concentrate on reading the sentences, and they were assured that no test of memory for the auditory material would follow. Each sound condition was played for 10 sec prior to the first trial of each sentence block, to prevent any orienting responses to the sound backgrounds from interfering with responses on early trials. The order of sound conditions and sentence blocks within sound conditions was counterbalanced using a Latin Square, such that each subject responded to all 320 sentences and experienced each sound condition, but no subject saw the same sentence more than once. The order of the 64 sentences within each block was randomized.

At the end of each block of 64 trials, subjects were given a 2-min break while the next block of trials and background sound cassette were set up. A longer break was given after the third block. Following completion of the fifth block of trials, subjects completed a brief spelling test to ascertain their knowledge of the homophones used in the sentence trials. This was a pencil-and-paper task in which subjects were required to fill in a missing word from a sentence by choosing between two homophones [e.g. *The truck* ——— *away the crane.* (*towed/toad*)] and the position of the correct homophone was randomized. The entire experiment lasted approximately 45 min.

Results

Spelling Knowledge Task

The spelling knowledge task was designed to establish whether subjects were acquainted with the correct spellings of homophones used in the unacceptable sentences. The overall error rate on this task was 1.7%, and 22 of the 40 subjects made no errors on the task. This error rate was very much lower than the error rates reported in the sentence evaluation task below. The only homophone pair to attract more than three errors was *fir/fur*, which generated nine errors. Thus the homophone error rate in the experimental task cannot be attributed to poor spelling knowledge on the part of the subjects.

Acceptable Sentences

Error Data. Mean percentages of errors for simple and complex acceptable sentences across the five sound conditions are presented in Figure 1. The errors on acceptable sentences were subjected to a 5 × 2 fully repeated-measures analysis of variance (ANOVA), with five levels of sound condition (speech, singing, singing + instrumental, instrumental, and quiet) and two levels of syntactic complexity (simple and complex). Analyses were performed both by subjects (reported as F_1) and by items (reported as F_2).[3]

[3] Because of a word-processing error, performance on a few sentences in some of the stimulus files (3 sentences in all) had to be excluded, and the analyses reported are based on the scores obtained after exclusion of these sentences.

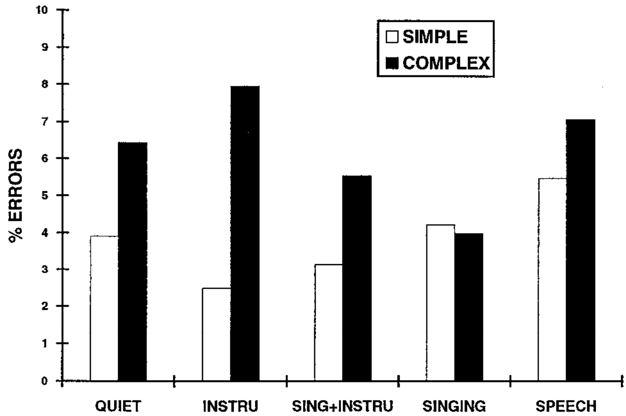

FIG. 1. Mean percentage of errors to simple and complex acceptable sentences across the five background sound conditions in Experiment 1.

The effect of sound condition on decision accuracy was not significant. Error rates were significantly greater for complex than for simple sentences, $F_1(1, 39) = 21.51$, $p < 0.001$; $F_2(1, 150) = 7.09$, $p < 0.01$. Syntactic complexity interacted significantly with sound condition in the by-subjects analysis, $F_1(4, 156) = 2.70$, $p < 0.04$, but the interaction was unreliable in the by-items analysis, $F_2(4, 600) = 2.33$, $p < 0.06$. This interaction arose because the difference in accuracy between simple and complex sentences was greater under some sound conditions than others. Figure 1 shows that the interaction was largely due to the substantial difference in accuracy between simple and complex sentences in the instrumental condition as compared to much smaller differences in the other conditions. In the speech and singing conditions the difference between simple and complex sentences was negligible. However, this interaction was only marginally reliable in the by-items analysis and there was no coherent pattern to it.

Reaction Time Data. Mean RTs to each sentence type across the five sound conditions appear in Table 1. Subjects' decision times to acceptable sentences were not significantly affected by type of background sound. Mean RTs were significantly faster to simple than to complex sentences, $F_1(1, 39) = 71.44$, $p < 0.001$, $F_2(1, 150) = 18.71$, $p < 0.001$. The Sound Condition × Complexity interaction was not significant.

Thus, none of the sound backgrounds significantly affected accuracy or speed of judgements to acceptable sentences. In contrast, syntactic complexity exerted a large effect on both accuracy and speed of judgements, with simple sentences being judged faster and more accurately than complex sentences.

Unacceptable Sentences

Error Data. Similar analyses were performed for errors and RTs on unacceptable sentences, except that homophony was added as a factor: Sentences with homophones were phonologically plausible, whereas those with control words were not. The mean

TABLE 1
Mean Acceptance RTs for Evaluation of Simple and Complex Acceptable Sentences Across the Five Background Sound Conditions in Experiment 1

	Sentence Type		
Condition	*Simple*	*Complex*	*Overall mean*
quiet	2809	2964	2886
instrumental	2788	3019	2903
singing + instrumental	2749	3032	2890
unaccompanied singing	2885	3070	2978
speech	2813	3094	2953
overall mean	2809	3036	

Note: Reaction times are given in milliseconds.

percentage of errors for each sentence type across the five sound conditions is presented in Figure 2. The sound conditions had no significant effects on error rates. Significantly more errors were made to simple than to complex sentences (14.16% and 11.31% respectively), $F_1(1, 39) = 19.73$, $p < 0.001$, but this difference was not significant by items. The main effect of homophony was also highly significant, $F_1(1, 39) = 49.16$, $p < 0.001$, $F_2(1, 76) = 21.15$, $p < 0.001$, with the percentage of errors to homophone sentences more than double that to control sentences (17.19% and 8.28%, respectively).

Among the interactions, only the Complexity × Homophony interaction was significant, $F_1(1, 39) = 11.19$, $p < 0.005$, but again it was not significant by items. This interaction reflected the fact that a significantly larger homophone effect (increased error

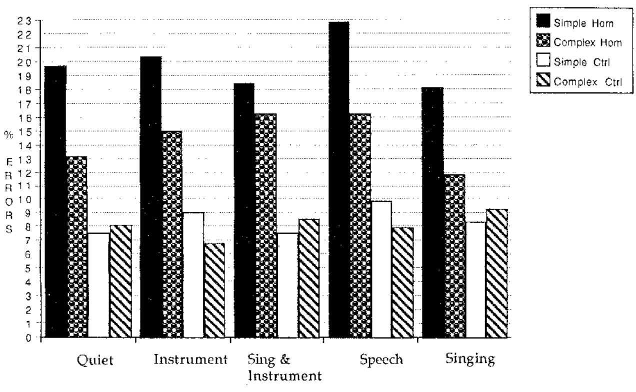

FIG. 2. Mean percentage of errors to simple and complex unacceptable sentences (containing homophones or orthographic control words) across the five background sound conditons in Experiment 1.

rates to homophone sentences) occurred for simple than for complex sentences, $t(39) = 5.42$, $p < 0.01$.

Reaction Time Data. Mean correct rejection RTs for each of the sentence types and sound conditions are shown in Table 2. The results of ANOVAs indicated that there was no significant effect of sound condition on performance, nor were the interactions of sound condition with complexity or homophony significant. There was a significant main effect of complexity in the by-subjects analysis only: Simple sentences were rejected faster than were complex sentences, $F_1(1, 39) = 7.47$, $p < 0.01$, $F_2(1, 76) < 1$. Sentences with inappropriate homophones were rejected faster than were sentences with control words, $F_1(1, 39) = 72.47$, $p < 0.001$, $F_2(1, 76) = 47.04$, $p < 0.001$. No other effects were significant.

Discussion

The most striking and unexpected finding of Experiment 1 was the failure of irrelevant speech and other vocal sounds significantly to impair reading comprehension. Neither accuracy nor decision time in sentence evaluation was adversely affected. This was particularly surprising given the subjects' (and experimenters') reports that the vocal conditions were very distracting and difficult to ignore.

Syntactic complexity of acceptable sentences did affect both accuracy and RTs, as it has done in previous research (Cook, 1975; Waters et al., 1987): Centre-embedded relative clause sentences were more difficult to comprehend than were right-branching relative clause constructions. Although there was a tendency for complex unacceptable sentences to be rejected more accurately than simple unacceptable sentences, the difference in accuracy was not significant in the item analysis, suggesting it was the product of a few sentences only.

TABLE 2
Mean Rejection RTs for Evaluation of Simple and Complex Unacceptable Sentences Across the Five Background Sound Conditions in Experiment 1.

	Sentence Type				
	Simple		*Complex*		
Condition	*Homophone*	*Control*	*Homophone*	*Control*	*Overall mean*
quiet	2553	2879	2580	2939	2738
instrumental	2595	2823	2539	3032	2747
singing + instrumental	2531	2787	2625	2966	2727
unaccompanied singing	2573	3010	2663	3055	2825
speech	2663	2932	2690	2987	2818
overall mean	2583	2886	2619	2996	

Note: Reaction times are given in milliseconds. Unacceptable sentences are those containing homophones or orthographic control words.

Homophony also affected decision accuracy. As in previous research, subjects made significantly more false alarms to sentences that sounded right, and the error rates to these sentences were comparable in level to those found with much shorter, single clause sentences (Coltheart et al., 1988, 1990; Coltheart, Avons, Masterson, & Laxon, 1991).[4] This error rate cannot be attributed to imperfect knowledge of the homophones used, as the error rates on the spelling knowledge test were very low (1.7%) as stated above. It therefore appears that a phonological code is generated, causing subjects to accept phonologically plausible homophone sentences erroneously. Earlier it was suggested that a phonological record might be more likely to be consulted when sentences are syntactically complex, resist immediate on-line interpretation, and possibly require back-tracking. If that were the case, it could be predicted that syntactically complex sentences containing inappropriate homophones would be more difficult to reject, because the phonological code does not discriminate between appropriate and inappropriate homophones. This did not occur: Syntactic complexity did not reliably affect rejection accuracy when sentences were unacceptable. Thus, syntactic complexity did not seem to increase reliance on a phonological code.

Correct rejections of unacceptable sentences were faster for those containing homophones than for those containing orthographic controls. That is, despite significantly more errors to phonologically plausible homophone sentences, the time taken correctly to reject these sentences was significantly less than that for the phonologically implausible control sentences. This finding has been reported in previous experiments (Coltheart et al., 1991), where it was argued that the phonological representation of the *inappropriate* homophone also activates that of the *appropriate* homophone, thus indicating which word should have been present in the sentence and facilitating the rejection process. This does not occur for the control sentences, because activation of the orthographic control word's phonology does not assist in determining what the appropriate word might have been; therefore subjects may spend time checking alternative interpretations before rejecting the sentence. This argument was also proposed by Daneman and Stainton (1991) to account for their finding that subjects in a proofreading task were more likely to correct inappropriate homophone substitutions than orthographic control substitutions. Evidence suggesting that subjects do attempt to determine what the appropriate word should have been comes from an eye-movement study (Daneman & Reingold, 1993) in which it was found that initial fixation time on inappropriate homophones and orthographic controls was comparable, and was longer than that on appropriate homophones; however, there were significantly more subsequent fixations and regressions to inappropriate orthographic control words than to inappropriate homophones. These results suggest that the phonology of the inappropriate homophone cues the appropriate word,

[4] Error rates on unacceptable sentences with homophones were almost identical for sentences in which the homophone was syntactically as well as semantically anomalous (18% on semantically anomalous sentences and 16% on semantically and syntactically anomalous sentences). This suggests that subjects did not merely base their decision on a superficial grammaticality judgement of the syntactic acceptability of the sentence. The phonology of the inappropriate word influenced subjects' decisions regardless of its syntactic acceptability.

facilitating the process of correction in the proofreading task (Daneman & Stainton, 1991) and rejection in the sentence judgement task.

The derivation of a phonological code in this sentence reading task was unaffected by concurrent irrelevant speech or singing. Thus, if irrelevant speech sounds (phonemes) gain obligatory access to a phonological short-term store and corrupt or replace its contents, this store may not contribute to the comprehension of the types of relative clause structures presented in Experiment 1. However, it is possible that the sounds used in Experiment 1 were ineffective in interfering with phonological working memory, even though subjects found them intrusive and hard to ignore. This possibility was examined in Experiment 2 in which the same sounds were presented during a short-term memory task.

EXPERIMENT 2

As mentioned earlier, previous research has shown that irrelevant speech and vocal music impair short-term serial recall of visually presented lists of numbers or letters (see Baddeley, 1986, 1990 for reviews). Additionally, studies have examined the effects of irrelevant sounds on the phonological similarity effect in ordered list recall (Colle & Welsh, 1976; Salamé & Baddeley, 1986). The phonological similarity effect refers to the finding that recall of phonologically similar lists of visually presented words or letters is inferior to recall of phonologically dissimilar lists (Baddeley, 1966; Conrad & Hull, 1964). Colle and Welsh (1976) manipulated phonological similarity using lists of eight consonants and examined the effects of irrelevant speech on ordered recall. They found a phonological similarity effect in silence and an increased error rate but no similarity effect with irrelevant speech, suggesting that the irrelevant speech had abolished the phonological similarity effect. Salamé and Baddeley (1986) investigated the effects of phonological similarity and irrelevant speech on ordered recall of consonant lists varying in length from 5 to 8 letters. They found that irrelevant speech impaired recall at all list lengths, and that a phonological similarity effect occurred only for list lengths 5 to 7. This phonological similarity effect was not abolished by irrelevant speech. Thus, the evidence for the effects of irrelevant speech on phonological coding is conflicting.

Consequently, Experiment 2 was designed to provide further evidence about the effects of irrelevant sounds on phonological coding in short-term memory. Baddeley's (1966) phonologically similar and dissimilar 5-word lists were used. Recall of these lists has yielded evidence of a strong phonological similarity effect in normal silent conditions (Baddeley, 1966; Coltheart, 1993), and this effect is abolished by concurrent articulation (Coltheart, 1993). The four sound conditions from Experiment 1 were again presented, along with a silent control condition. Thus, Experiment 2 investigated whether the irrelevant speech, singing, and music presented in Experiment 1 were capable of disrupting ordered short-term recall of word lists, and whether irrelevant speech and singing interfered with phonological similarity.

Method

Subjects

Thirty-five first-year Behavioural Sciences students ranging in age from 18 to 52 participated in the study for course credit. All reported normal hearing and normal or corrected-to-normal vision, and all were native English speakers.

Stimulus Tasks and Conditions

The memory tasks consisted of 25 phonologically similar and 25 phonologically dissimilar lists of 5 words each. The lists were constructed from a set of 10 similar words (*mad, mat, man, map, max, cad, cat, can, cap, cab*) and a set of 10 dissimilar words (*cow, day, bar, few, hot, pen, sup, pit, rig, bun*) used by Baddeley (1966, Experiment 3). No word appeared more than once in a list, and words occurred equally often in the 25 lists.

The five sound backgrounds from Experiment 1 were used, namely: (1) a quiet (control) condition, (2) instrumental music, (3) singing with instrumental accompaniment, (4) unaccompanied singing, and (5) continuous speech. Within each of the five sound conditions, subjects were presented with five similar and five dissimilar lists in random order. Order of presentation of sound backgrounds and lists within sound backgrounds was counterbalanced.

Apparatus and Procedure

Each subject was tested individually in a single session, with a 1-min break between each sound condition and the next. As in Experiment 1, subjects wore headphones through which the sound backgrounds were presented at approximately 75 dB(A). Subjects were instructed to ignore any background sounds they might hear and were reassured that there would be no test of their memory for the auditory material. The sound presentation began 10 sec before the first list in each block, as in Experiment 1.

The word lists were presented on an IBM personal computer using Dmastr software (Forster & Forster, 1990) programmed to present similar and dissimilar lists in a different random order to each subject. Each list was preceded by a 1-sec fixation point, after which words were presented successively in the centre of the screen for 1 sec, each immediately replacing the previous word. Immediate written recall was required after every list, using a provided booklet. Each page in the booklet contained a column numbered from 1 to 5, and subjects wrote each word next to the number corresponding to its serial position in the list. It was emphasized that only words recalled in their correct serial position would be scored as correct. Following recall, subjects initiated presentation of the next list. Five practice trials in silence preceded the experimental trials.

Results

The mean percentages of words correctly recalled in similar and dissimilar lists across the five sound conditions appear in Figure 3. A two-factor repeated-measures ANOVA yielded the following results. Recall of phonologically similar lists (48.6%) was significantly worse than recall of dissimilar lists (73.3%), $F(1, 34) = 191.00$, $p < 0.0001$. The main effect of sound was also highly significant, $F(14, 136) = 7.85$, $p < 0.001$. Planned comparisons using the Bonferroni procedure showed that the vocal conditions impaired recall when compared to silence, $t(136) > 4.0$, $p < 0.001$ for each comparison, whereas instrumental music did not. Recall in the instrumental condition showed a tendency to be better than recall in any of the vocal conditions, but these comparisons just failed to reach significance. The Phonological Similarity × Sound Condition interaction was not significant, $p > 0.1$. Thus, the phonological similarity effect was present in all five sound conditions.

It has been suggested that the phonological similarity and irrelevant speech effects in short-term memory tasks arise only when both item *and* order information are required at recall (Baddeley, 1990; Morris & Jones, 1990b; Watkins, Watkins, & Crowder, 1974). Therefore another method of scoring was applied, wherein a word was counted as correctly recalled regardless of whether it was recalled in its correct serial position. It should be noted, however, that this second scoring procedure cannot be equated with free recall as the task required of subjects was serial recall.

The mean percentage of correct recall for similar and dissimilar lists across the five sound conditions appears in Figure 4. Comparison of means with those using the serial recall scoring method shows that overall recall is higher when serial order is disregarded. A repeated-measures ANOVA showed the main effect of phonological similarity to be highly significant, $F(1, 34) = 130.49$, $p < 0.0001$, with recall of similar lists (67.3%) significantly worse than recall of dissimilar lists (81.9%). The main effect of sound condition was once again highly significant, $F(4, 136) = 5.00$, $p < 0.001$. However, these main effects must be interpreted in the light of the significant Phonological Similarity × Sound Condition interaction, $F(4, 136) = 3.58$, $p < 0.01$. First, it must be noted that recall of phonologically similar lists was significantly worse than recall of dissimilar lists in every sound condition, $t(170) > 5.00$, $p < 0.001$ in every case. The interaction arises because of the greater effect of sound on the dissimilar than on the similar lists. Planned comparisons showed that performance on the similar lists did not differ significantly across the five sound conditions. For the dissimilar lists, performance was worse in sound than in quiet. The following comparisons were significant: quiet versus singing+instrumental; quiet versus singing; quiet versus speech; and instrumental versus singing, $t(272) > 2.83$, $p < 0.05$ in each case. Thus, although the phonological similarity

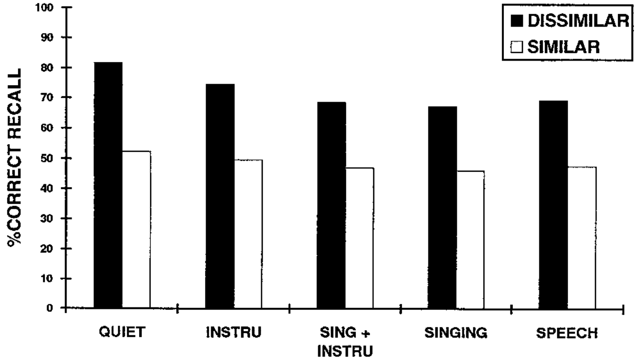

FIG. 3. Mean percentage of correct recall (correct serial position) for phonologically similar and dissimilar word lists across the five background sound conditions in Experiment 2.

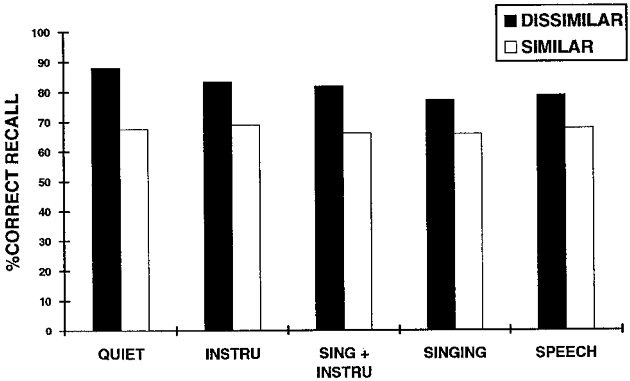

FIG. 4. Mean percentage of correct recall (serial position disregarded) for phonologically similar and dissimilar word lists across the five background sound conditions in Experiment 2.

effect was significant across all sound conditions, the magnitude of the effect was reduced in the vocal conditions.

Discussion

The results of Experiment 2 showed conclusively that the irrelevant sound conditions presented in Experiment 1 were effective in reducing ordered recall in short-term memory tasks. This extends the irrelevant speech effect to sub-span lists of words (in addition to lists of digits or letters). Furthermore, it appears that vocal sounds interfered more strongly with recall than did instrumental music, which did not greatly reduce recall. Differences among the various vocal conditions (speech, unaccompanied and accompanied singing) were slight and not significant. This confirms the results obtained by Salamé and Baddeley (1989) and supports the view that some property specific to auditory verbal material allows it to gain access to the phonological component of working memory.

In accord with previous research, phonological similarity of list items impaired recall. However, as in Salamé and Baddeley (1986), this phonological similarity effect was maintained in all the sound conditions, suggesting that irrelevant vocal sounds do not prevent phonological recoding of visually presented words and probably do not prevent rehearsal. When recall was scored without regard to order, the vocal conditions (compared to quiet) were found to reduce (but not abolish) the effect of phonological similarity, and the overall level of recall was higher. This suggests that rather than having been corrupted or replaced, list items are in fact retained, albeit in the wrong order. This in turn implies that the effect of irrelevant speech is not one of preventing or interfering with encoding of items in the phonological short-term store or replacing items currently held there (Salamé & Baddeley, 1986), but, rather, is one of interfering with the maintenance of item order information (see also Jones, 1993; Jones & Morris, 1992). This suggestion is supported by the findings of Salamé and Baddeley (1990) that irrelevant speech disrupted serial but not free short-term recall of a list of words, and by Morris and Jones (1990b), who found it was only the serial component of a short-term memory list recall task that was susceptible to interference by irrelevant speech.

CONCLUSIONS

Experiment 1 examined the effects of various irrelevant vocal sounds (speech, accompanied and unaccompanied singing) and instrumental music on reading comprehension of two-clause sentences differing in syntactic complexity. The contribution of phonological coding to reading comprehension was assessed by the inclusion of unacceptable sentences that were either phonologically plausible (containing inappropriate homophones) or phonologically implausible (containing orthographic controls). Irrelevant sounds did not reliably impair sentence comprehension performance; however, syntactic complexity and phonology did affect performance. Sentences with complex structure were more difficult to comprehend, but there was no indication that syntactic complexity provoked a greater reliance on the phonological representation of a sentence. This is consistent with Waters et al. (1987), who found that concurrent articulation did not interfere with complex sentences to a greater extent than with simple sentences. Evidence of the derivation of a phonological code during sentence reading was manifest in an increase in error rates on unacceptable homophone sentences that sounded acceptable. The derivation of this phonological code was unaffected by the presence of irrelevant vocal sounds.

Failure to find adverse effects of irrelevant speech and singing on reading comprehension was not due to an inability of the sounds to affect cognitive processes in general, and phonological working memory in particular. In Experiment 2, the same sound conditions were presented concurrently with a short-term memory task. Irrelevant vocal sounds, but not instrumental music, impaired ordered recall of 5-word lists. Similar effects have been reported for these sorts of sounds on ordered recall of digit and letter lists (e.g. Salamé & Baddeley, 1989). Phonological similarity of list items also impaired recall, and this effect was present under all the concurrent sound conditions. Thus, in both Experiments 1 and 2, phonological coding of visually presented words seems to be possible in the presence of irrelevant vocal sounds. These findings raise questions about the view that speech input gains obligatory, automatic access to a phonological short-term store and that it occupies slots in that store or replaces information currently stored there. Rather than interfering with the items themselves or preventing their storage within the phonological store, the specific effect of irrelevant vocal sounds would appear to be on the ability to maintain item order information. If this is the case, the seemingly puzzling finding of clear phonological (homophone) effects without any corresponding interference by irrelevant speech may be explained: An interference effect may only be observed when the task requires the retention of exact serial order of items in working memory. Presumably, only the short-term memory task made this demand.

A final point of interest is that concurrent articulation has been found to remove phonological (homophone) effects in sentence reading (Coltheart et al., 1990), whereas in this study irrelevant speech failed to do so. These differences between the effects of irrelevant speech sounds and concurrent articulation can be explained by Monsell's (1987) model. Monsell proposed that the functions of the "phonological loop" are carried out by recirculating information between the two sub-lexical phonological buffer stores, one in the speech input processing pathway and one in the speech output processing pathway. The generation of irrelevant speech by the subject interferes with both the production of phonological codes for the list items and their maintainance by rehearsal. Irrelevant speech heard by the subject interferes with the retention of phonological codes in the input buffer but does not impede the orthographical-to-phonological conversion process, or the immediate activation of meaning by its output. Of course, it is likely that irrelevant vocal sounds have other effects, and Martin et al.'s (1988) research indicated that the semantic content of irrelevant speech reduced the retention of factual information from prose passages. It is also possible that the comprehension of material requiring more extensive backtracking than the types of sentences used in this experiment (such as garden-path sentences) might be adversely affected by irrelevant vocal sounds, but this remains to be investigated.

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APPENDIX

SIMPLE		COMPLEX		SIMPLE		COMPLEX	
Homophone	Control	Homophone	Control	Homophone	Control	Homophone	Control
aisle	issue	banned	bank	loot	late	missed	mast
alter	alto	beet	belt	maize	mane	mown	moon
bawl	bill	blue	bled	male	mate	navel	nail
beech	belch	bolder	balder	manner	maker	pail	pave
birth	beret	breaks	breeds	maul	malt	pawed	pained
bizarre	bazooka	bury	belly	past	passage	pear	peer
board	brood	cheep	cheer	paste	paged	rode	raid
check	cheek	cord	charred	peace	pence	rows	robs
coarse	choose	court	couch	plain	plate	sail	salt
doe	dot	cowered	covered	rote	rate	stares	staves
due	dug	duct	dumped	raise	rats	storey	stony
eight	sight	flours	floors	sent	seat	suites	swept
farther	fatter	fort	font	serial	ceramic	sure	short
fate	feet	fowl	foal	sighed	signed	sword	scared
genes	gains	fur	fin	straight	stretched	thrown	throat
hare	hale	gait	gale	taut	tight	toad	toned
haul	hail	heard	hard	through	thought	tract	truce
heel	hell	hole	while	vale	veal	wade	wide
kernel	kennel	main	mean	whale	wool	war	wire
leek	lurk	meet	moat	yolk	joke	week	work