

Short article

Irrelevant speech effects and statistical learning

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Immediate serial recall of visually presented verbal stimuli is impaired by the presence of irrelevant auditory background speech, the so-called irrelevant speech effect. Two of the three main accounts of this effect place restrictions on when it will be observed, limiting its occurrence either to items processed by the phonological loop (the phonological loop hypothesis) or to items that are not too dissimilar from the irrelevant speech (the feature model). A third, the object-oriented episodic record (O-OER) model, requires only that the memory task involves seriation. The present studies test these three accounts by examining whether irrelevant auditory speech will interfere with a task that does not involve the phonological loop, does not use stimuli that are compatible with those to be remembered, but does require seriation. Two experiments found that irrelevant speech led to lower levels of performance in a visual statistical learning task, offering more support for the O-OER model and posing a challenge for the other two accounts.

Keywords: Irrelevant speech effect; Working memory; Short-term memory; Statistical learning.

In the typical irrelevant speech experiment (e.g., Colle & Welsh, 1976), immediate serial recall of short lists of visually presented items is impaired if presentation is accompanied by irrelevant

speech (for a review, see Neath, 2000). The irrelevant sounds are truly irrelevant to the task and, indeed, need not be comprehensible or even linguistic. The subjects are never asked any questions

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whatsoever about the irrelevant information; rather, they are usually told that sometimes they will hear sounds and that they should ignore them. The surprising result is that recall can be reduced by 10–50% relative to an appropriate control condition. This effect has attracted considerable attention because it is a quintessential example of cross-modal interference: Irrelevant auditory stimuli interfere with relevant visual stimuli. Despite a growing literature, there remains considerable debate about how best to explain the effects. The two studies reported here are designed to test differing predictions of the three main accounts, as only one predicts that irrelevant speech will affect visual statistical learning.

It is important to note that an increasing number of studies have tested the idea that the irrelevant speech effect is simply a result of distraction. The distraction hypothesis has not fared well. First, a distraction account predicts that the disruptive effect of irrelevant speech should increase as the intensity of the irrelevant speech increases. However, the magnitude of the effect is equivalent whether the irrelevant speech is 40 dB(A) or 76 dB(A) (Colle, 1980). Second, a distraction account predicts habituation to irrelevant speech or, at the very least, that some diminution of the detrimental effects is possible. However, there is no evidence for such habituation (Jones, Macken, & Mosdell, 1997). Third, irrelevant speech effects are observed regardless of whether the irrelevant speech occurs during list presentation or during the retention interval (Miles, Jones, & Madden, 1991), indicating that co-occurrence is not a necessary prerequisite for the effect. Fourth, a general distraction account predicts a larger effect when the irrelevant items are less predictable than when they are more predictable. However, the magnitude of the effect is unrelated to the predictability of the irrelevant stimuli (Tremblay & Jones, 1998). Finally, attentional capture manipulations are functionally distinct from the disruption caused by irrelevant speech. For example, attentional capture manipulations disrupt performance on tasks that show no disruptive effect of irrelevant speech (Hughes, Vachon, & Jones, 2007).

Theoretical accounts of the irrelevant speech effect

The phonological loop hypothesis

According to Baddeley's (2003) working memory framework, the locus of the irrelevant speech effect is within the phonological loop. This is made up of the phonological store, which stores information in a speech-like code, and the articulatory control process. While an earlier account emphasized masking of phonological information within the phonological store by phonemes from the irrelevant stream, the current account emphasizes interference between the irrelevant information and the representation of both item and order information. There are two key features to this account: First, it can account for irrelevant speech effects only when the to-be-remembered information is stored in the phonological loop, and, second, it requires invoking an attentional mechanism that detracts from the processes required to store and maintain the to-be-remembered items (Page & Norris, 2003).

The feature model

According to the feature model (Neath, 2000), items are represented in memory as a vector of features. At test, the subject has degraded cues representing the items that were presented and must interpret or reintegrate these cues using information in secondary memory. Two factors contribute to the irrelevant speech effect. First, ignoring the irrelevant stimulus requires attention in the dual-task sense: The more effort required to ignore or not process the secondary stimulus, the more a subject's performance should be reduced. Second, features from the irrelevant information can be adopted into the representation of a to-be-remembered item, reducing the probability of successfully matching a degraded memory trace to a particular cue. However, if the to-be-remembered items differ too much from the irrelevant items, it becomes less likely that feature adoption will occur.

The object-oriented episodic record model

The object-oriented episodic record (O-OER) model of Jones and colleagues (Jones &

Tremblay, 2000) identifies the locus as a conflict between order information in multiple streams. Perceptual processing creates a stream of amodal objects linked by pointers. Objects are created when new stimuli are processed. If an item is repeated 10 times, only one object is created, whereas if 10 different items are presented, 10 objects are created. In the typical irrelevant speech experiment (i.e., an immediate serial recall task), one stream of objects represents the irrelevant speech, and another stream of objects represents the to-be-remembered items. Errors occur when the two streams interfere. A key prediction from this account is that irrelevant speech effects should occur only when the items that comprise the irrelevant speech change in some fashion. That is, if a single token, *ba*, is repeatedly played as the irrelevant speech, only one object will be created, and this will not readily interfere with the objects formed by the to-be-remembered items. However, if a series of different tokens are played, *ba ga pa*, and so on, then an object will be created for each, and interference will occur. This changing-state effect has been demonstrated numerous times (see Neath, 2000, for a review).

One way in which the three accounts differ is in the predicted scope of the irrelevant speech effect. The phonological loop hypothesis requires the to-be-remembered items to be processed by the phonological loop, whereas the feature model requires some level of compatibility between the irrelevant and the to-be-remembered items such that feature adoption is feasible. In contrast, the O-OER model predicts that irrelevant speech effects will be observed whenever the main task requires seriation. One such task is statistical learning.

Statistical learning

The term “statistical learning” was first used by Saffran, Aslin, and Newport (1996) to refer to the finding that 8-month old infants can learn

quite complex statistical relationships about an auditory stream of syllables.¹ The stream of sound appeared to be a random sequence of syllables (e.g., *pabikugolatudaropitibudodaropigolatu...*) but over the course of the two-minute sequence, certain sequences of three syllables (or triplets) always occurred in the same order, such as *bikugo* (*bi* followed by *ku* followed by *go*). At test, the infants successfully discriminated among the recurring triplets and two other kinds: those that they had never heard in sequence (called impossible triplets), and those triplets that occurred in sequence by chance but did not always follow one another (called possible triplets). The learning is termed “statistical” because the infants learned about the joint probabilities of occurrence of various syllables.

This result has been replicated and expanded to include nonlinguistic auditory stimuli (Creel, Newport, & Aslin, 2004), visual stimuli (Fiser & Aslin, 2002), and even learning of nonadjacent dependencies (Newport, Hauser, Spaepen, & Aslin, 2004). Similar results have also been obtained when the participants were cotton-top tamarins (*Saguinus oedipus*), a primate native to the rainforests of Colombia (Newport et al., 2004). Statistical learning is commonly viewed as a “domain general” ability (Keidel, Jenison, Kluender, & Seidenberg, 2007; Perruchet & Pacton, 2006)—that is, as a basic mechanism applicable to widely different stimuli, modalities, tasks, and subject populations.

In the demonstrations of statistical learning that use nonlinguistic stimuli, it is not plausible to assume that memory for the information learned is dependent on the phonological loop or that feature adoption is likely, and, therefore, according to both the phonological loop hypothesis and the feature model, performance on these visual statistical learning tasks should not be affected by irrelevant speech. In contrast, the O-OER account holds that tasks should be susceptible to disruption by irrelevant speech as long as they emphasize or require seriation. Because

¹ We note, however, other earlier uses, such as Estes’s (1950) statistical learning theory.

the order of events is a critical feature of statistical learning, the task does require seriation and therefore, according to the O-OER model, should be susceptible to the disruptive effects of irrelevant speech.

In order to demonstrate that irrelevant speech can affect performance on a statistical learning task, it is necessary to use a between-subjects design. One group of participants observes the stimuli in quiet conditions (i.e., no irrelevant speech), and performance of that group is compared to that of a second group of participants, which experiences irrelevant speech during presentation. We have previously shown (Farley, Neath, Allbritton, & Surprenant, 2007) that robust irrelevant speech effects obtain in a between-subject design.

EXPERIMENT 1

Experiment 1 was based on a simplification of an experiment reported by Turk-Browne, Jungé, and Scholl (2005). Observers saw a continuous stream of shapes (see Figure 1); unbeknownst to the observers, the stream was made up of four triplets. For ease of exposition, it is convenient to label these as ABC, DEF, GHI, and JKL. Within the stream, B always followed A, and C always followed B. Thus, part of the stream could be ...ABCGHIABCDEFJKL... Each triplet preceded and followed every other triplet equally often. At test, two sequences of three shapes each were shown, and the observers were asked to indicate which stream seemed the most familiar. There were three types of triplets tested. An “always” test triplet was made up of three shapes that always appeared in succession (i.e., ABC, DEF, etc). An “impossible” test triplet was made up of three shapes that never appeared in succession. For example, the triplet ADG is impossible because D never followed A, and G never followed D. A “possible” test stream was made up of three shapes that could have appeared in succession by chance, but were not designed to do so. For example, the triplet BCG could occur, because C always followed B, and G

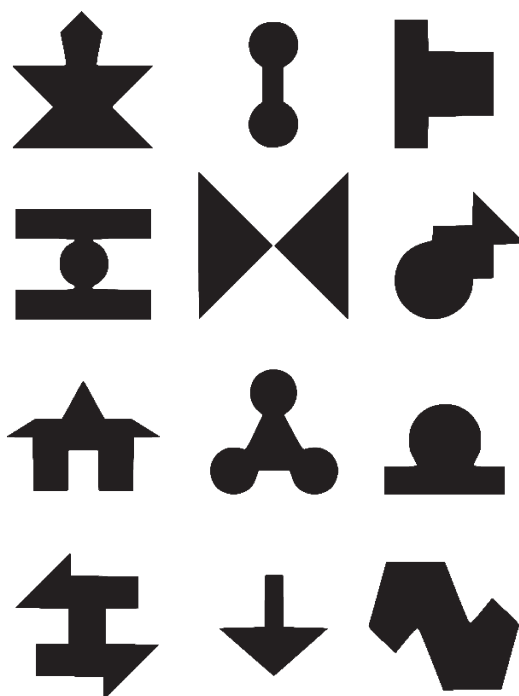


Figure 1. The 12 shapes grouped into one possible set of triplets.

is the start of a second triplet. There were thus three test types: always versus impossible (A v I), always versus possible (A v P), and possible versus impossible (P v I).

Method

Participants

A total of 50 undergraduates from Memorial University of Newfoundland volunteered to participate in exchange for a small honorarium. Each was randomly assigned to one of two conditions.

Stimuli

The 12 basic shapes, shown in Figure 1, were taken from Fiser and Aslin (2002). The stimuli were drawn using computer software within a 128×128 -pixel square. The irrelevant speech tokens were 19 letters (*a, e, i, o, u, w,* and *z* excluded) spoken by a female, digitized at 44 kHz.

Design

There was one between-subjects variable—presence or absence of background irrelevant speech—and one within-subjects variable—type of test comparison (always vs. possible; always vs. impossible; and possible vs. impossible).

Procedure

For each participant, the 12 shapes were randomly divided into four triplets. During the presentation phase, the shapes were shown centred in the middle of a computer screen for 800 ms each followed by 200 ms of blank screen. Each shape was shown equally often, and each triplet followed and preceded every other triplet equally often (6 times each). In the noise condition, a continuous stream of letters was played at a rate of 800 ms stimulus onset asynchrony (SOA) with the constraint that a letter could not be played twice in a row. Presentation of the letters in the irrelevant speech stream was not synchronized to presentation of the shapes. The irrelevant speech was played only during the presentation phase, which lasted just under 4 minutes.

The observers were informed that they would see a long sequence of shapes and that further instructions would be given afterwards. They were also asked to wear headphones and to ignore any sounds that they might hear. The volume was set to a comfortable level. After the initial sequence of shapes had been presented, the test phase began, and the following instructions were shown on the computer screen:

For the next part of the experiment you will see two sequences of shapes. Each sequence will contain 3 shapes. Please decide which sequence seems the most familiar to you. For example, if the first sequence of 3 shapes seems more familiar than the second, please click on the “First” button.

The label “First” appeared, followed by three shapes at the same rate as in the presentation phase. Then, the label “Second” appeared, followed by three more shapes. The observer then made a response to indicate which sequence seemed the most familiar by clicking on one of

two appropriately labelled buttons using a mouse. There were 24 questions, 12 with the most common sequence first and 12 with the most common sequence second. There were 8 questions of each type, and the questions were presented in random order. The test phase was self-paced, and participants were tested individually. For all analyses, an alpha level of .05 was adopted.

Results and discussion

Figure 2 shows the proportion of times the observers selected the most frequently occurring triplet. The error bars show 95% confidence intervals (Masson & Loftus, 2003). As is clear in the figure, performance in the quiet condition was more accurate than chance, indicating that the observers learned the statistical properties of the sequence. In contrast, performance was worse in the irrelevant speech condition and indeed was close to chance levels.

The data were analysed using a 2 (group: no irrelevant speech vs. irrelevant speech) \times 3 (test type: always vs. possible, always vs. impossible,

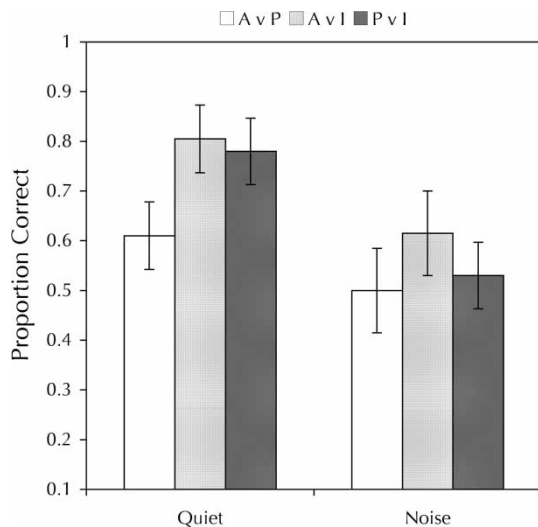


Figure 2. Proportion of correct judgements of familiarity as a function of comparison type (always vs. possible, *A v P*; always vs. impossible, *A v I*; and possible vs. impossible, *P v I*) and as a function of whether presentation was accompanied by irrelevant speech. Note: Error bars show 95% confidence intervals.

possible vs. impossible) analysis of variance (ANOVA). There was a main effect of group, $F(1, 48) = 26.55$, $MSE = 0.05$, partial $\eta^2 = .356$, reflecting better performance in the quiet condition (proportion correct .732) than in the irrelevant speech condition (.548). There was also a main effect of test type, $F(2, 96) = 11.72$, $MSE = 0.03$, partial $\eta^2 = .196$. Performance was best on the always versus impossible comparisons (.710), worst on the always versus possible comparisons (.555), and in between for the possible versus impossible comparisons (.655). The interaction was not reliable, $F(2, 96) = 2.34$, $MSE = 0.03$, partial $\eta^2 = .046$.

Tukey HSD tests showed that in the quiet condition, performance was significantly worse on the always versus possible tests than on either of the other two, which did not differ from each other. In the irrelevant speech condition, performance did not differ on the three different tests.

EXPERIMENT 2

Experiment 1 showed the standard pattern of results for a statistical learning experiment in the quiet condition, but performance in the irrelevant speech condition was impaired. One important characteristic of the irrelevant speech effect is the changing-state effect, the finding that irrelevant auditory stimuli that change over time produce a decrement whereas otherwise comparable stimuli that do not change generally do not produce a decrement (e.g., Miles et al., 1991). Experiment 2 was designed to replicate the results of Experiment 1, but also to determine whether a changing-state effect is observable. Therefore, there were three conditions: quiet, with no irrelevant speech; unchanging, which had one randomly chosen letter played continuously; and changing, which had a stream of different randomly chosen letters and was identical to the irrelevant speech condition used in Experiment 1. If the data observed in Experiment 1 reflect the classic irrelevant speech effect, then we expect Experiment 2 to demonstrate a changing-state effect, with performance in the quiet and unchanging conditions

equivalent, and performance in the changing condition significantly worse.

Method

Participants

A total of 93 undergraduates from Memorial University of Newfoundland and the College of New Jersey volunteered to participate in exchange for a small honorarium or for course credit. Each was randomly assigned to one of three conditions, and none had participated in Experiment 1.

Stimuli

The stimuli were the same as those in Experiment 1.

Design

The only change in design was including an additional between-subjects factor such that there were three levels of background noise: no irrelevant speech, unchanging irrelevant speech, or changing irrelevant speech.

Procedure

The procedure was identical to that of Experiment 1 except for the following. In the unchanging condition, one letter was chosen randomly for each participant, and the letter was played over headphones repeatedly at a rate of 800 ms SOA. The changing condition was the same as the irrelevant speech condition in Experiment 1: a continuous stream of letters were played at a rate of 800 ms SOA with the constraint that a letter could not be played twice in a row. One additional change in procedure was made in an attempt to boost overall performance and to bring the instructions more in line with those used in other studies. Rather than just stating that further instructions would be given after presentation, the observers were instructed to watch the sequence "so that they would be able to answer questions about what they saw" (Fiser & Aslin, 2002, p. 461).

Results and discussion

Figure 3 shows the proportion of times the observers correctly selected the most frequently

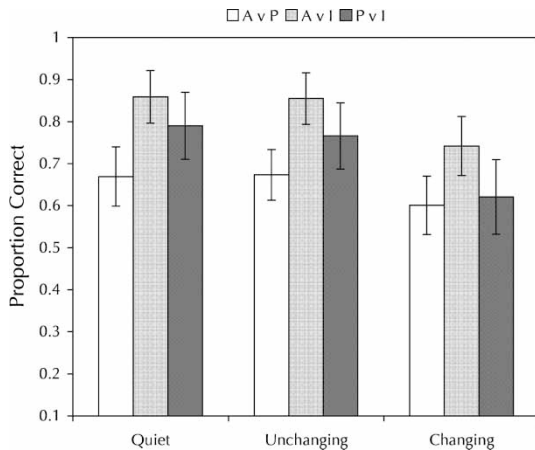


Figure 3. Proportion of correct judgements of familiarity as a function of comparison type (always vs. possible, *A v P*; always vs. impossible, *A v I*; and possible vs. impossible, *P v I*) and as a function of type of irrelevant speech.

Note: Error bars show 95% confidence intervals.

occurring triplet, and the error bars show 95% confidence intervals (Masson & Loftus, 2003). Performance in all conditions for all types of comparisons was better than chance and also better than performance in Experiment 1. More importantly, as is clear in the figure, accuracy was reduced if changing irrelevant speech occurred during presentation but was unaffected if unchanging irrelevant speech was played. Experiment 2, then, shows both an irrelevant speech effect and a changing-state effect in a visual statistical learning task.

The data were analysed using a 3 (group: no irrelevant speech, unchanging irrelevant speech, changing irrelevant speech) \times 3 (test type: always vs. possible, always vs. impossible, possible vs. impossible) ANOVA. There was a main effect of group, $F(2, 90) = 6.26$, $MSE = 0.06$, partial $\eta^2 = .122$, due to worse performance in the changing condition (proportion correct .655) than in either the quiet condition (.773) or the unchanging irrelevant speech condition (.765). There was also a main effect of test type, $F(2, 180) = 26.67$, $MSE = 0.03$, partial $\eta^2 = .229$. As in Experiment 1, performance was best in the always versus impossible test (.819), worst in the always versus possible test (.648), and in between

for the possible versus impossible test (.726). The interaction between group and test type was not reliable, $F(4, 180) < 1$.

Three planned comparisons evaluated the hypothesis that for each type of test, performance in the quiet and unchanging irrelevant speech conditions did not differ, whereas performance in the changing irrelevant speech condition was significantly worse. The comparison for always versus possible did not quite reach conventional levels of significance, $F(1, 90) = 3.10$, $MSE = 0.03$, $.10 > p > .05$, even though the means are in the predicted direction, and the 95% confidence intervals also support this prediction. For both of the other tests, however, the planned comparisons were significant: for always versus impossible, $F(1, 90) = 8.76$, $MSE = 0.03$; for possible versus impossible, $F(1, 90) = 9.81$, $MSE = 0.05$.

GENERAL DISCUSSION

Irrelevant auditory speech disrupts visual statistical learning: Observers were less accurate at judging which of two sequences was presented more frequently when presentation was accompanied by irrelevant speech than in a quiet control condition. Just as with immediate serial recall, a changing-state effect was also observed: a single, repeating irrelevant item did not impair performance whereas a changing stream of irrelevant items did reduce performance. These results are important in a number of ways.

First, the results of both experiments add further evidence in support of the O-OER model and against the accounts of both working memory and the feature model. Accounts based on the phonological loop have no way to account for irrelevant speech effects observed when the to-be-remembered items are unlikely to be processed by the phonological loop. Similarly, the feature model has difficulty accounting for the results as the to-be-remembered items are so different from the irrelevant speech that it is unlikely that feature adoption would occur. In contrast, the O-OER model explains the result by noting that the visual statistical learning task

involves seriation, and when irrelevant speech is present, there is the opportunity for the two streams to interfere. As in the immediate memory situation, the changing-state effect arises because a single repeating item creates only one object, not a stream of objects. It may be possible for both working memory and the feature model to be extended to account for data from statistical learning paradigms, but currently, it is not obvious how this would be done.

Second, the results are consistent with other results demonstrating that effects once identified as being a hallmark of a particular memory system (or subsystem) can sometimes be observed in situations in which that memory system is unlikely to play a role (for a review, see Surprenant & Neath, 2008). While irrelevant speech effects have been demonstrated most often in traditional short-term or working memory tasks, the effects are not limited to just those tasks.

Third, this paradigm may offer a way to examine further the many different facets of attention and how they affect statistical learning. As noted above, results from studies on irrelevant speech effects observed with immediate serial recall test are generally inconsistent with a distraction or dual-task account. It is possible that the locus of the irrelevant speech effect is different in statistical learning tasks from how it is in immediate serial recall tasks, and that all that is happening is the result of reduced attention. After all, attention is critical to statistical learning (Turkewitz et al., 2005). However, the question is ultimately empirical. The many tests of this idea using immediate serial recall have produced results that make a general attentional account of irrelevant speech effects untenable. A similar series of studies using statistical learning would reveal whether it is tenable in this domain. If the attentional view is correct, then one should find that decreasing the predictability of the irrelevant speech leads to more interference with statistical learning, and that increasing the intensity of the irrelevant speech leads to more interference with statistical learning. If the O-OER account is correct, then one should find that such manipulations have no effect on statistical learning, just as

they have no effect on immediate serial recall (Colle, 1980; Tremblay & Jones, 1998).

A final interesting speculation arising from these results is whether this paradigm could be used to assess whether nonhuman animals show an irrelevant speech effect. Nonhuman primates show statistical learning (e.g., Newport et al., 2004), and we have shown that irrelevant speech affects visual statistical learning. If irrelevant speech effects are found in nonhumans, it would be highly problematic for accounts of the irrelevant speech effect that invoke the phonological loop. Our research facilities permit the study only of human primates, so this speculation is left to others to examine.

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