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Cross-modal negative priming and interference in selective attention

JON DRIVER
University of Cambridge, Cambridge, England

and

GORDON C. BAYLIS
University of California, San Diego, California

This study examined whether negative priming and Stroop interference can be observed cross-modally, resulting from auditory distractors that are related to subsequent visual targets. Negative priming was found in subjects who remained unaware of the contingency between distractors and subsequent targets, whereas subjects who reported the contingency showed facilitatory priming. Stroop interference from incongruent auditory distractors was observed across all subjects and was replicated in a second experiment which also showed that interference declined when a particular distractor was repeated. These data suggest that an inhibitory mechanism of selection may operate to prevent response to auditory distractors, similar to the inhibitory selection mechanisms proposed for vision. They also demonstrate the reality of cross-modal Stroop effects, contrary to the findings of Miles, Madden, and Jones (1989).

Studies of human selective attention are concerned with how people select a subset of available perceptual information to control their responses. Although the level of processing at which selection takes place remains controversial, most authors agree that ignoring a stimulus is a passive process. Neisser (1976, p. 87) provides a strong statement of this view: "What then happens to unattended information? In general nothing happens to it.... We simply don't pick it up."

An alternative view holds that unattended information is actively inhibited (Neill, 1977; Tipper & Driver, 1988). The negative priming effect provides prima facie support for such inhibition. This effect was first observed by Neill (1977) in a variant of the Stroop task. When the color to be named on trial $n+1$ is the same as the color word that has been ignored on trial n, a delay is observed; this delay is taken to reflect continued inhibition of some representation of the previously ignored word. Analogous effects have since been observed for line drawings or digits, with selection being cued by color (Driver & Tipper, 1989; Tipper, 1985; Tipper & Driver, 1988). Tipper and Driver (1988) found negative priming when an ignored drawing was followed by an attended visual word that was the name of the ignored object. The lack of any physical resemblance between the drawing and the word suggests that this effect arose at an abstract level of representation. The present study examines whether negative priming can be observed between an auditory distractor and a subsequent visual target.

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In addition to examining the impact of auditory distractors on response to a *subsequent* visual target, in our first experiment we investigated whether auditory distractors can interfere with responses to a *simultaneous* visual target. The existence of Stroop (1935) interference from one modality to another has a controversial history. Broadbent (1982, p. 284) asserted that "it is hard to imagine that selectivity cannot be reduced to one sense excluding the other." More recently, Miles, Madden, and Jones (1989) argued on theoretical grounds that cross-modal Stroop effects should never be observed. Contrary to these suggestions, there is some positive evidence for the existence of cross-modal interference effects. For example, Greenwald (1972) had subjects name a series of visual digits while they ignored a concurrent stream of auditory distractors. He reported a Stroop effect from auditory distractors that were incongruent digits. However, the interfering digit was always preceded throughout the series by auditory clicks. An orienting response to the first speech sound in the series might therefore have produced the interference, as noted by Broadbent (1982, p. 284). To preclude this possibility, we compared the interference from *sequences* of auditory digits on visual digit naming with the distraction produced by sequences of speech that did not include digits.

Greenwald (1972) also observed an effect that it is tempting to interpret as cross-modal negative priming. When an auditory digit was repeated throughout a series, response to the visual target at the end of the series was delayed if it corresponded to the auditory digit. Unfortunately, the successive repetition of the digit as a distractor throughout the series means that habituation to the auditory distractors may occur. Thus the increased response latency might reflect cross-modal habituation, rather than the inhibition that is held to produce negative priming (see Lorsch, Anderson, & Well, 1984; Reisberg, Baron, &

Kemler, 1980). In our first experiment, we extended the Greenwald (1972) paradigm to include the crucial negative priming condition, in which an *unrepeated* auditory distractor corresponds to the visual digit at the next position.

EXPERIMENT 1

Method

Subjects. The 24 subjects (17 female, 7 male) were paid volunteers from the Oxford subject panel. All reported normal or corrected-to-normal acuity and normal hearing.

Apparatus and Materials. The stimuli were generated on an Acorn BBC microcomputer (Model B+). Auditory distractor stimuli were generated with an Acorn BBC speech system, which consists of a speech processor and a ROM with prestored words and word parts, all in the same voice. The stimuli employed were the digits 1, 2, 3, 4, 5, 6, 8, and 9, as well as a nonsense vowel sound ("uh"). They were presented to both ears at about 70 dB over a pair of monaural headphones connected to a Marantz Superscope CD-330 cassette recorder, which served as an amplifier. Visual target stimuli were the digits 1, 2, 3, 4, 5, 6, 8, and 9 presented in Teletext double size characters on a Microvitec Cub 895 Monitor. At a viewing distance of 90 cm, the average visual angles were .4° horizontal and .7° vertical. Additional visual materials were a fixation cross and a hash mark used as a visual mask. The stimulus series consisted of nine successive visual targets and nine auditory distractors, which were each presented concurrently with a visual target. Naming reaction times (RTs) to the visual stimuli in Positions 2-9 for each series were taken in milliseconds with the use of a TTL voice key. A hand-held microswitch was used by subjects for starting each stimulus series.

Design. A within-subjects design was employed, in which the independent variable was the relationship of the auditory distractors in a series to the visual targets in a series. Concurrent and successive targets and distractors were completely unrelated, except as noted. The three types of series, exemplified in Figure 1, were as follows.

Baseline. The nine auditory distractors in a series were all the nonsense vowel sound "uh."

Interference. The distractors were all digits. The target and distractor at position n in a series always were different from the target and distractor at position $n+1$ in the series.

Ignored repetition. The distractors were all digits, and the distractor at position n in a series had the same identity as the target at position $n+1$. In an effort to prevent subjects from noting this contingency, it only applied to Positions 4-7 in each series. At the other positions in a series, the relationships were as in the interference condition.

Procedure. When subjects pressed the microswitch, they saw and heard a sequence of events as follows.

1. A fixation cross presented for 500 msec.
2. A visual target presented for 100 msec, and a "concurrent" auditory distractor. Distractor onset preceded target onset by 150 msec, giving approximate phenomenal simultaneity.
3. The hash-mark mask presented for 1,000 msec.

This sequence was repeated nine times to produce each stimulus series, with a stimulus-onset asynchrony (SOA) for successive visual targets in a series of 1,600 msec. The subjects were instructed to name the visual digits as quickly and accurately as possible. The experimenter typed the subjects' responses on line into the microcomputer, which scored their accuracy. At the end of each series, the number of errors and the sum of the eight RTs recorded was displayed for 2 sec (the first response in the series was not recorded). It was stressed that the auditory distractors should be completely ignored, because they would otherwise make the task more difficult, and because the experiment was concerned with resistance to distraction. After six practice series, subjects were given six blocks of 12 series each. Within each block, each condition appeared four times in an otherwise random order.

The experiment lasted approximately 45 min, after which subjects were asked a series of questions. The first was, "Did you notice that the auditory distractors were sometimes digits?" If the response was "yes," they were then asked, "Did you notice any relationship between these auditory digits and the visual digits in a series?" If the response was "no," or if the subjects failed to specify the contingency of the ignored repetition condition, they were then asked, "Did you notice that the auditory digits in the middle of a series sometimes predicted the very next visual digit?"

All the subjects reported noticing that the auditory distractors could be digits. Ten of the subjects accurately described the ignored repetition contingency in response to the second question (i.e., they reported that "in the middle" of the series the auditory digits "sometimes" predicted the visual digits). These 10 subjects will henceforth be referred to as *cognizant*. The remaining 14 *naive* subjects protested ignorance of the ignored repetition contingency even when prompted by the third question.

Visual Targets									
	2	9	4	9	3	6	8	2	1
Auditory Distractors									
Ignored Repetition	1	5	9	3	6	8	5	9	3
Interference	4	1	2	5	1	2	3	9	4
Baseline	Uh	Uh	Uh	Uh	Uh	Uh	Uh	Uh	Uh

Figure 1. Examples of stimulus series for the three conditions of Experiment 1. A series of visual targets is shown at the top, with concurrent auditory distractors appropriate to the different conditions shown beneath.

Results

Although the data from all positions in a series are relevant to the comparison of the baseline and interference conditions, the contingency in the ignored repetition condition only applies for Series Positions 4-7. For this reason, separate analyses were performed on the data from Positions 2-9 and on the data from Positions 4-7 only. The means of subjects' median RTs are shown in Table 1 for each condition, along with the corresponding error rates.

It is clear that the number of positions that are included makes little difference to these results. The low error rates were not analyzed further. A one-way within-subject analysis of variance (ANOVA) on the RT data showed that there was a highly significant effect of condition when Positions 2-9 were included [$F(2,48) = 28.0, p < .01$]. A planned Wilcoxon test was carried out on these data to look for any cross-modal Stroop interference. This confirmed that the interference condition was significantly slower than the baseline condition ($T = 29.5, p < .01$).

Inspection of the means in Table 1 for Positions 4-7 shows little evidence of an overall negative priming effect. However, this is scarcely surprising, since the 10 cognizant subjects at some point became aware of the ignored repeti-

Table 1
Means of Subjects' Median Reaction Times (in Milliseconds) for Naming the Visual Targets in Experiment 1, With Corresponding Error Rates

	Positions 4-7		Positions 2-9	
Condition	RT	% Errors	RT	% Errors
Ignored repetition	430	.4	432	.4
Interference	427	.8	430	.5
Baseline	412	.8	411	.8

Table 2
Means of Cognizant and Naive Subjects' Median Reaction Times at Positions 4-7 in Experiment 1, With Corresponding Error Rates

	Cognizant		Naive	
Condition	RT	% Errors	RT	% Errors
Ignored repetition	424	.2	434	.5
Interference	432	.3	424	1.1
Baseline	404	1.0	418	.7

tion contingency. They could thereafter use the auditory distractors they had been requested to ignore to predict the visual targets in the middle of a series, and would therefore be expected to show facilitatory rather than negative priming. For this reason, a two-way mixed ANOVA was run on the data for Positions 4-7, with condition as a within-subjects factor, and cognizant/naive as a between-subjects factor. This showed that there was no main effect of cognizance [$F(1,23) = .1$, n.s.], a significant effect of condition [$F(2,46) = 22.0$, $p < .01$], and a significant interaction [$F(2,46) = 7.1$, $p < .01$]. The means of subjects' median RTs and error rates for Positions 4-7 are shown in Table 2 separately for the cognizant and naive groups.

Newman-Keuls tests were used to interpret this interaction. The naive subjects showed significant negative priming ($p < .01$), while the cognizant subjects showed facilitatory priming ($p < .05$). The cognizant subjects showed significant Stroop interference ($p < .01$), but the naive subjects only showed a trend toward interference. The cognizant subjects were faster than the naive in the baseline condition ($p < .01$).

Discussion

A significant negative priming effect was found for the naive subjects, who were unaware of the ignored repetition contingency. This result demonstrates that negative priming may occur between stimuli in different modalities, suggesting that auditory distractors can achieve supramodal levels of representation. Facilitatory rather than negative priming was found in the cognizant subjects, who also showed the most substantial interference effect. Since the cognizant group became aware of the ignored repetition contingency at some point, it is possible that they were monitoring the auditory stimuli in order to predict the visual targets. This strategy could explain the facilitatory priming they showed in the ignored repetition condition, and the relatively large Stroop effect they showed in the interference condition, where the auditory distractors do not correctly predict the visual targets.

Thus, the overall interference effect we observed might be primarily attributable to strategic monitoring of auditory stimuli by the cognizant subjects, rather than to any intrinsic difficulty in filtering out auditory distractors. Since the existence of cross-modal interference effects is controversial (Cowan, 1989a, 1989b; Miles & Jones, 1989; Miles et al., 1989), we ran a second experiment to test whether cross-modal Stroop effects could be observed under conditions where there should be no strategic monitoring of the auditory distractors.

Table 3
Means of Subjects' Median Reaction Times in Experiment 2, With Corresponding Error Rates

Condition	RT	% Errors
Interference	423	.7
Redundant distractor	414	.3
Baseline	396	.5

EXPERIMENT 2

Method

Two alterations were made from Experiment 1. First, the ignored repetition condition was omitted so that subjects could never predict visual targets by monitoring auditory distractors. Second, a redundant distractor condition was added, in which the auditory distractors were repetitions of a single digit throughout the series. This was included because previously the interference condition differed from the baseline in two ways, distractor repetition and distractor identity. The redundant distractor condition allows separation of the repetition and digit-versus-nondigit factors.

Two minor methodological differences from Experiment 1 were that four digits (1, 2, 4, and 9) were employed as stimuli compared with the eight used previously, and the SOA between successive visual targets in a series was increased to 2,100 msec, the mask being displayed for 1500 msec.

Twelve new subjects (6 male) were recruited from the same source as before. All reported normal or corrected acuity and normal hearing.

Results

The results are summarized in Table 3. The low error rates were not analyzed further. A one-way within-subjects ANOVA on the RT data for Positions 2-9 showed that there was a significant effect of condition [$F(2,22) = 13.0$, $p < .01$]. Planned Wilcoxon tests confirmed that RTs were longer in the interference condition and the redundant distractor condition than in the Baseline ($T = 0$, $p < .01$, and $T = 1$, $p < .01$, respectively). The interference condition gave slower RTs than did the redundant distractor condition ($T = 8.5$, $p < .01$).

Discussion

In the present experiment, auditory distractors never predicted the visual targets, so monitoring them could not benefit performance. Nevertheless, significant cross-modal interference was still observed. This suggests that strategic monitoring of auditory distractors is not required for cross-modal interference. This interference was still present, but reduced, when the auditory distractors were repetitions of the same digit. This extends prior demonstrations within the visual modality that Stroop interference declines with distractor repetition (Reisberg et al., 1980).

GENERAL DISCUSSION

We have shown that auditory information cannot be perfectly filtered when subjects are attending to visual information, even though the relevant and irrelevant information are distinguished by modality of input. Experiment 1 extends previous demonstrations of abstract negative priming (e.g., Tipper & Driver, 1988) by showing that the effect can arise cross-modally. Response to a visual target was delayed when it corresponded to the immediately preceding auditory distractor, provided that subjects were unaware of this contingency. This implies that auditory distractors are inhibited at a level of representation that is sufficiently abstract to be shared with visual targets.

Subjects who reported noticing the ignored repetition contingency in Experiment 1 showed facilitatory rather than negative priming and also showed more interference from concurrent auditory distractors. This pattern of results suggests that they may have been strategically monitoring the auditory distractors. Tipper and Baylis (1987) proposed that some individuals suppress distracting information more efficiently than others. Good selectors will tend to show relatively small interference effects from distractors by distractor suppression, which in turn produces relatively large negative priming effects. Conversely, poor selectors will show more interference, but little or no negative priming. This is consistent with our observations in Experiment 1, where the individuals who showed negative priming were less susceptible to interference than were the individuals who did not show negative priming. In terms of this model, negative priming could be observed in the absence of interference effects (see Driver & Tipper, 1989). It would be interesting to examine in future research whether cross-modal negative priming can be found when cross-modal Stroop effects have not been observed (see, e.g., Miles et al., 1989).

Our observation of a cross-modal Stroop effect is consistent with Cowan and Barron's (1987) finding that the naming of ink colors is disrupted by irrelevant auditory color words. Cross-modal interference was also found in Experiment 2 under conditions in which distractors never predicted targets, suggesting that the effect is not purely strategic. However, Miles et al. (1989) argued on theoretical grounds that cross-modal Stroop effects should be observed only when rehearsal of the visual items is required. They argued (p. 77) that "perceptual tasks such as the Stroop task, which do not require use of the articulatory loop for rehearsal purposes, should not be similarly susceptible." One difficulty with this position is that ink-color naming or digit naming are by no means pure "perceptual" tasks. Both require an appropriate phonological code to be derived. Auditory distractors that are associated with a different phonological code could in principle disrupt this process. It is emphatically not the case that cross-modal Stroop effects require that "irrelevant speech works by impairing the perception of visual material," as implied by Miles et al. (1989, p. 79) but later retracted by Miles and Jones (1989, p. 85).

The remaining challenge to the reality of cross-modal interference is empirical. In four experiments, Miles and colleagues failed to observe cross-modal interference effects from irrelevant speech on responses to visual stimuli. One (Miles et al., 1989, Experiment 2) can be dismissed because the distractors were not incongruent with the visual targets and so would not have been expected to produce a Stroop effect by any theory. Another study (Miles et al., 1989, Experiment 1A) cannot be considered evidence against Cowan and Barron (1987), since a nonsignificant trend toward a cross-modal Stroop effect was found. However, two studies (Miles & Jones, 1989; Miles et al., 1989, Experiment 1B, 1989) produced absolutely no evidence for cross-modal interference. On the other hand, cross-modal Stroop effects have been found in many experiments, including those of Cowan and Barron (1987) and Cowan (1989a); previous studies by Morton (1969), Greenwald (1972), Lewis (1972), and Navon (1977), which have curiously been overlooked in the recent debate; and, of course, the two experiments in this paper. One aspect of the method used by both Miles and colleagues (Miles & Jones, 1989; Miles et al., 1989) and Cowan and associates (Cowan, 1989a; Cowan & Barron, 1987) suggests why the effect is not always apparent. Their auditory distractors were tape-recordings of words spoken at a particular rate. Many visual targets were presented simultaneously for self-paced naming in a prespecified sequence. Thus the temporal relationship between targets and distractors, known to be critical to whether Stroop effects are observed within the visual modality (M. O. Glaser & W. R. Glaser, 1982; W. R. Glaser & Dungelhoff, 1984), was left to chance. A further problem with this self-paced method of visual presentation is that it allows some auditory distractors to coincide with the processing of *congruent* targets. The most recent "distracting" auditory color word will correspond to the ink color to be named for 1 in every 4 targets in Experiments 1A and 1B of Miles et al. (1989) and would therefore be expected to *facilitate* response to the visual target rather than disrupt it. In view of these methodological problems, and given the weight of all the positive evidence, the cross-modal Stroop effect can no longer be considered a "fallacy," contrary to the findings of Miles and Jones (1989).

We have argued that our cross-modal interference and negative priming effects require that the auditory distractors reach a supramodal level of representation. One possibility is that interference effects arise because of response competition at the stage of producing an articulatory code. Allport (1980) has argued that the repetition of spoken words is exceptionally compatible, to the extent that heard words may automatically evoke their spoken form in the listener via a "privileged loop" (McLeod & Posner, 1984). If so, cross-modal negative priming and interference should not be seen when a different modality of response to the visual targets is required or when subjects have to ignore visual information while responding verbally to auditory stimuli.

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