

Auditory, visual, and cross-modal negative priming

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Auditory, visual, and cross-modal negative priming was investigated using a task in which participants judged whether stimuli were animals or musical instruments. Negative priming was observed, but only if the attended and the ignored primes evoked different responses. This pattern—negative priming after conflict, but not after nonconflict, primes—was demonstrated with visual stimuli and replicated with auditory stimuli, as well as across modalities, both auditory to visual and visual to auditory. Implications for theories of negative priming are discussed.

Negative priming refers to the phenomenon that a reaction to a stimulus can be slowed down or more likely to be in error if the stimulus has recently been ignored. There is abundant research on this phenomenon, but empirical investigations have focused selectively on the visual domain (the typical stimuli being letters, words, color bars, simple geometric shapes, line drawings of objects, etc.; see Houghton & Tipper, 1994). The lone exception until recently was a study by Banks, Roberts, and Ciranni (1995), who successfully demonstrated auditory negative priming, in that pronunciation of an auditorily presented word was delayed if that word had been overheard on the preceding trial. Given the scarcity of research on auditory negative priming, it is not surprising that the situation is no better for investigations of the phenomenon across modalities. To our knowledge, only Driver and Baylis (1993, Experiment 1) have investigated cross-modal negative priming, but only the auditory-to-visual side of it. They found that ignoring a spoken single-digit number increased the time needed to pronounce that digit when it was presented visually on the next trial. However, negative priming was observed only for a small subgroup of 14 (out of 24) participants, who were classified as *unaware* of the ignored repetition contingency. This leaves some uncertainty as to the reality of cross-modal negative priming and calls for an independent replication and extension to the visual-to-auditory modality switch.

In the present experiment, participants saw or heard pairs of stimuli. One stimulus in each pair had to be classified as *animal* or *musical instrument*. Each trial con-

sisted of a prime and a probe stimulus pair. Given two possible categories, the attended and the to-be-ignored stimuli of each pair could be from the same category and, thus, require the same response (*nonconflict* pair), or they could be from different categories and, thus, require different responses (*conflict* pair). Varying conflict versus nonconflict for both prime and probe pairs yielded four different trial types: (1) trials with nonconflict primes and probes, (2) trials with nonconflict primes and conflict probes, (3) trials with conflict primes and nonconflict probes, and (4) trials with conflict primes and probes.

METHOD

Participants

The participants were 284 undergraduate students (198 female), between 18 and 58 years of age ($M = 23$). They were tested individually and were paid for their participation.

Materials

The auditory stimuli were four animal sounds (singing bird, chicken, frog, and lamb) and four sounds of musical instruments (English horn, guitar, piano, and drum). Each tone was 300 msec long, complete with attack and decay. The participants heard the tones over earphones plugged directly into an Apple Power Macintosh computer.

The visual stimuli were line drawings of the same animals and instruments that fitted into a 6.5×6.5 cm square. They were presented in red or blue on a white background.

On an auditory trial, a 20-msec metronome click indicated the ear (left or right) of the following to-be-attended tone. On a visual trial, a red or a blue square (1.7×1.7 cm) indicated the color of the to-be-attended line drawing.

The participants reacted to the to-be-attended stimuli by pressing the *instrument* (arrow-up) or the *animal* (arrow-down) key on the computer keyboard. These keys were aligned sagittally so as to avoid spatial compatibility effects between the tone's location and the required response.

Each trial consisted of a prime and a probe display. Each display consisted of a target and a simultaneously presented distractor. Trial types can be categorized according to whether the attended target and the ignored distractor were associated with the same response

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category (henceforth, *NC* for *nonconflict*) or with different response categories (henceforth, *C* for *conflict*). There were 96 prime/probe trials of each type: *NC/NC*, *NC/C*, *C/NC*, and *C/C*. Within each of these trial types, 48 were ignored repetition trials, and 48 were control trials.

The algorithm used to construct the stimulus configurations for different trial types is illustrated in Table 1. First, an adequate set of stimuli was constructed for the ignored repetition trials in the *NC/NC* condition. All other stimulus types were then generated from this set. The 48 different ignored repetition trials in the *NC/NC* condition were obtained by systematically combining the four different stimuli for each of the two response categories. Let the numbers from 1 to 4 denote the four different stimuli of one response category. Then the sequence 1–2–2–3 may denote the composition of one particular trial in terms of the attended prime (1), the ignored prime (2), the attended probe (2), and the ignored probe (3). Because the same stimulus is presented as the ignored prime and the attended probe, 24 such sequences are possible (1–2–2–3, 1–2–2–4, . . . , 4–3–3–2) for each of the two response categories.

For each ignored repetition trial, a control trial was constructed by replacing the ignored prime with the stimulus that did not occur on the ignored repetition trial (I–4 replaced I–2 in the example in Table 1). Filler trials were constructed for both the ignored repetition (labeled “Filler Type I” in Table 1) and the control (“Filler Type II”) trials in order to avoid the possibility that the response category of the probe could be predicted from the prime display. These filler trials were identical to the ignored repetition and control trials, except that the attended probe was replaced by the stimulus with the same ordinal number as that from the other response category (e.g., A–2 replaced I–2 in the example in Table 1).

Trials in the *NC/C* condition were parallel to those in the *NC/NC* condition, except that the ignored probe was replaced by the stimulus with the same ordinal number as that from the other response category (A–3 replaced I–3 in the example in Table 1). Trials in the *C/NC* condition were parallel to those in the *NC/NC* condition, except that the attended prime was replaced by the stimulus with the same ordinal number as that from the other response category (A–1 replaced I–1 in the example in Table 1). Finally, in the *C/C* condition, both the attended prime and the ignored probe were replaced by the stimuli with the same ordinal numbers as those from the other response category (A–1 and A–3 replaced I–1 and I–3, respectively, in the example in Table 1).

The algorithm just described results in 768 different trials (192 ignored repetition trials, 192 control trials, and 384 filler trials) that have several desirable features. For instance, each stimulus occurs equally often in the ignored repetition, the control, and each of the

two sets of filler trials. The same holds for the frequencies with which different stimuli co-occur as prime pairs, as probe pairs, and as the two successive to-be-attended stimuli of a trial. Also note that the response category of the ignored prime was always the same on an ignored repetition and its corresponding control trial. This implies that any performance differences between control and ignored repetition trials must be due to the stimulus identity and cannot be due to the response category associated with it. Furthermore, the probe stimulus pair was identical for an ignored repetition trial and its matching control trial, thus enabling an unequivocal comparison of the probe reactions.

Varying the modalities in which the primes and the probes were presented (visual–visual, auditory–visual, visual–auditory, and auditory–auditory) created four different presentation conditions. Presentation side (left or right) and color (red or blue) of the attended prime was determined randomly on auditory and visual prime trials, respectively. On ignored repetition trials, the ignored primes and the attended probes were always presented in the same color in the visual–visual presentation condition and to the same ear in the auditory–auditory condition.

Procedure

The participants were familiarized with the visual–acoustic appearance of the stimuli by simultaneously presenting each line drawing and the associated sound at least four times, but the participants could invoke these presentations as often as they wished. They initiated the training phase when the stimuli felt “familiar enough.” The participants first reacted to one stimulus at a time. Each stimulus occurred at least twice. Subsequently, the participants reacted to 40 pairs of simultaneously presented stimuli. The presentation modality of a stimulus pair was determined by the experimental condition. The task was to classify the target as *instrument* or *animal* while ignoring the distractor. The reactions to at least 17 of the last 20 practice trials had to be correct. Otherwise, the participants were asked to repeat the training phase.

The experiment consisted of 768 trials, each composed of a prime and a probe pair of stimuli. The participants pressed the *animal* or the *instrument* key to indicate, as quickly as possible, but without making errors, the category of the attended stimulus in each pair.

In the visual–visual condition, a central 100-msec colored dot cue indicated the color in which the to-be-attended line drawing was to be presented (red or blue, randomly determined). After a 400-msec cue–target interval, the prime pair of superimposed line drawings, one red and one blue, was presented for 300 msec. The participants reacted by quickly pressing the appropriate key. The dot cue for the probe pair of stimuli was presented 500 msec after that reaction.

Table 1
Examples of Stimulus Configurations in Experiment 1

Stimulus	Ignored Repetition		Control		Filler Type I		Filler Type II	
	Attended	Ignored	Attended	Ignored	Attended	Ignored	Attended	Ignored
<i>NC/NC</i>								
Prime	I–1	I–2	I–1	I–4	I–1	I–2	I–1	I–4
Probe	I–2	I–3	I–2	I–3	A–2	I–3	A–2	I–3
<i>NC/C</i>								
Prime	I–1	I–2	I–1	I–4	I–1	I–2	I–1	I–4
Probe	I–2	A–3	I–2	A–3	A–2	A–3	A–2	A–3
<i>C/NC</i>								
Prime	A–1	I–2	A–1	I–4	A–1	I–2	A–1	I–4
Probe	I–2	I–3	I–2	I–3	A–2	I–3	A–2	I–3
<i>C/C</i>								
Prime	A–1	I–2	A–1	I–4	A–1	I–2	A–1	I–4
Probe	I–2	A–3	I–2	A–3	A–2	A–3	A–2	A–3

Note—The letters A and I refer to the *animals* and musical *instruments*, respectively. Numbers 1 to 4 represent the four different stimuli assigned to one category (English horn, guitar, piano, and drum; singing bird, chicken, frog, and lamb). *NC*, nonconflict; *C*, conflict.

The timing of events for the probe pair was identical to that for the prime pair.

In the auditory–auditory condition, the 20-msec click indicated which ear had to be attended to (left or right, randomly determined). After a 480-msec cue–target interval, the prime pair of tones was presented for 300 msec, one to the left and one to the right ear. The cue click for the probe pair of stimuli was presented 500 msec after the prime response. The timing of events for the probe pair was identical to that for the prime pair.

The timing of the events was parallel for auditory–auditory and visual–visual trials. Therefore, the sequence of events in the auditory–visual and the visual–auditory conditions follows from the descriptions of the conditions in which the stimuli were presented in one modality only.

Prime or probe reactions faster than 100 msec or slower than 4,000 msec were defined as invalid, and the entire trial was repeated. After each trial, the participants were informed about the correctness of their reactions. After the experiment, all the participants were informed about its purpose.

Design

The independent variables were presentation condition (visual–visual, auditory–visual, visual–auditory, and auditory–auditory; between subjects) and trial type (NC/NC, NC/C, C/NC, and C/C; within subject). With 71 participants in each presentation condition, negative priming effects of $d_z = 0.40$ could be detected given $\alpha = \beta = .05$.¹ The level of α was set to .05 for all analyses.

RESULTS

Probe reaction times were evaluated only for trials in which both the prime and the probe reactions were correct. The means of the participants' average probe reaction times and error rates are presented in Figure 1.

The raw performance measures are not of primary interest, but a quick description of their main features is useful. Most obviously, (1) probe reactions were faster after visual than after auditory probes (669 vs. 897 msec), whereas prime modality did not have an effect, and (2) probe reactions were slower following conflict, as opposed to nonconflict, probes (819 vs. 747 msec). Also, this probe conflict effect was larger for auditory (939 vs. 854 msec) than for visual (698 vs. 640 msec) stimuli, and it was larger after nonconflict primes (843 vs. 751 msec) than after conflict primes (795 vs. 743 msec). It may be interesting to note that the probe modality and probe conflict effects on the probe reaction times were paralleled by prime modality and prime conflict effects on the prime reaction times (not depicted in Figure 1). Prime reactions were faster after visual than after auditory primes (725 vs. 966 msec). Prime reactions were also slower following conflict than following nonconflict primes (872 vs. 819 msec), and this prime conflict effect was larger for auditory (1,002 vs. 930 msec) than for visual (742 vs. 707 msec) stimuli. The error data showed a similar performance pattern, except that probe modality did not play a role.

In sum, large effects on the performance measures were exerted by whether or not the attended and the ignored stimuli implied conflicting responses and by the presentation modality. The central question, however,

concerns the priming effects—that is, the differences in the performance measures between control and ignored repetition trials. Figure 2 illustrates these differences.

A preliminary analysis showed that the error differences between control and ignored repetition trials did not differ from zero for any of the trial types in the visual–visual, the auditory–visual, and the visual–auditory conditions [$t(70)$ values ranging from 1.01 to -1.83]. In the auditory–auditory condition, this was the case only for the C/NC trial type [$t(70) = -1.81$]. Error differences were significantly above zero for the NC/NC and the NC/C trial types [$t(70) = 2.71$ and 2.00 , respectively], and they were significantly below zero for the C/C trial type [$t(70) = -2.21$]. However, the error pattern in the auditory–auditory condition was consonant with the performance pattern expressed by the reaction time data. Thus, we may conclude that an interpretation of the reaction time data is not complicated by possible speed–accuracy tradeoffs.

At a descriptive level, the pattern of negative priming effects in the probe reaction times seems quite clear, in that the difference between control and ignored repetition trials was consistently negative only when preceded by a conflict prime. Indeed, this difference was significantly below zero for the C/NC and the C/C types of trials in the visual–visual condition [$t(70) = -3.10$, $d_z = 0.35$, and $t(70) = -5.81$, $d_z = 0.69$, respectively], in the auditory–visual condition [$t(70) = -2.12$, $d_z = 0.25$, and $t(70) = -2.41$, $d_z = 0.29$, respectively], in the visual–auditory condition [$t(70) = -2.07$, $d_z = 0.25$, and $t(70) = -2.67$, $d_z = 0.32$, respectively], and in the auditory–auditory condition [$t(70) = -4.60$, $d_z = 0.55$, and $t(70) = -4.54$, $d_z = 0.54$, respectively].

The situation is markedly different for probe reactions that followed a nonconflict prime. The critical reaction time difference was not significantly different from zero for NC/NC and NC/C types of trials in the visual–visual condition [$t(70) = 0.99$ and -0.52 , respectively], in the auditory–visual condition [$t(70) = -0.38$ and 0.54 , respectively], and in the visual–auditory condition [$t(70) = 0.60$ and 0.78 , respectively]. The difference between control and ignored repetition trials was actually positive for the NC/NC and the NC/C trial types in the auditory–auditory condition [$t(70) = 7.03$, $d_z = 0.83$, and $t(70) = 2.83$, $d_z = 0.34$, respectively].

Thus, there is clear evidence of negative priming, but only on prime conflict trial types. We may, then, ask whether negative priming on prime conflict trials is modulated by whether or not there is a probe conflict. Descriptively, the overall absolute difference between control and ignored repetition trials was larger for conflict (36 msec) than for nonconflict (25 msec) probes, but the divergence between those conditions seems to have been small. In order to increase the statistical power of the test of a possible probe conflict effect, the four presentation conditions were tested simultaneously. In such an analysis, we may also test hypotheses about the relative sizes of the negative priming effects as a function of the pre-

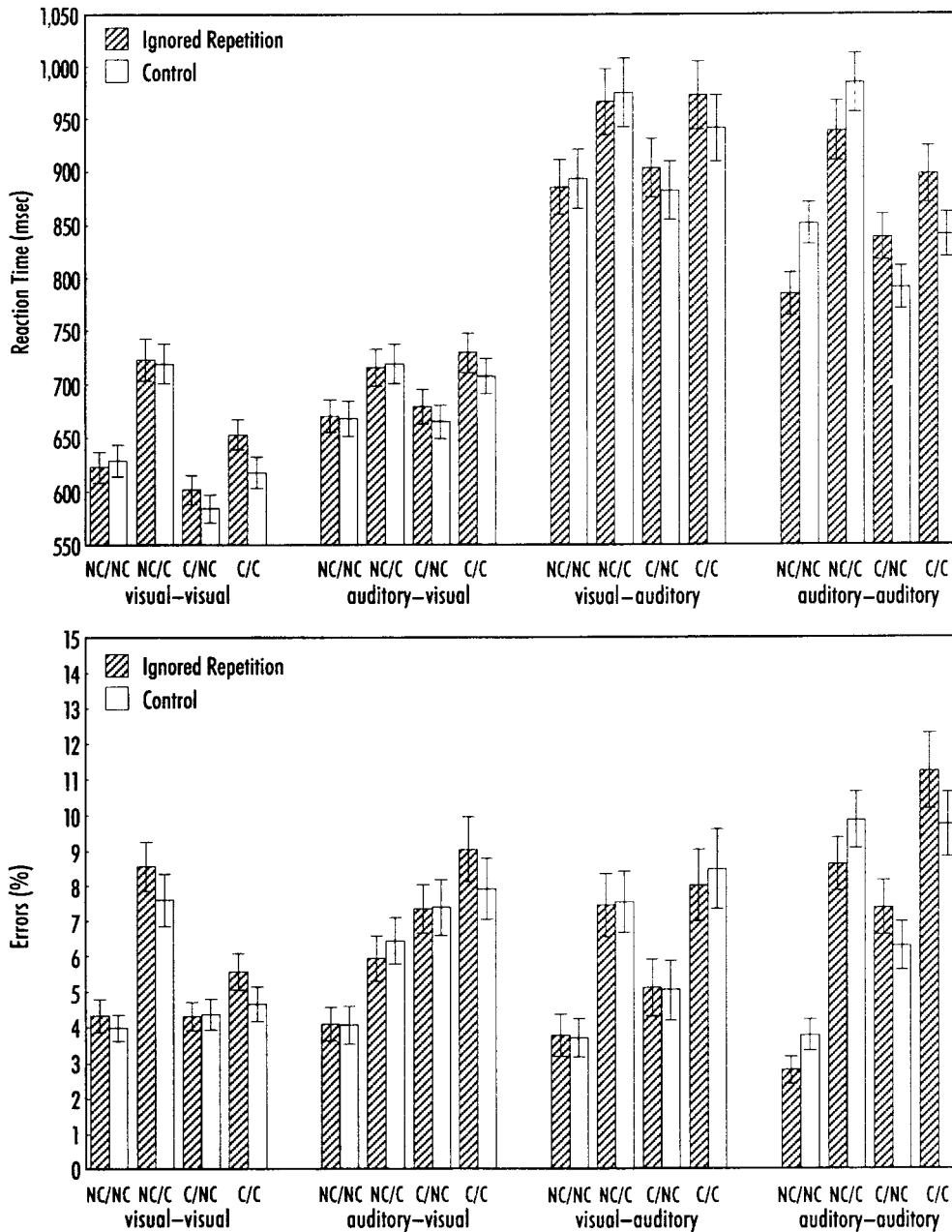


Figure 1. Mean probe reaction times and error percentages as a function of presentation condition (visual-visual, auditory-visual, visual-auditory, and auditory-auditory; between subjects) and trial type (NC represents nonconflict primes/probes, C represents conflict primes/probes). The error bars depict the standard errors of the means.

sensation condition. Descriptively, the effect seems to have been largest for the auditory-auditory condition (-52 msec), followed by the visual-visual condition (-27 msec), the visual-auditory condition (-26 msec), and the auditory-visual condition (-18 msec). A 4 × 2 analysis of variance with presentation condition as a between-subjects variable and probe type as a within-subjects variable showed that the probe type variable failed to reach the conventional level of significance

[$F(1,280) = 2.85, MS_e = 6,175, p > .09$]. The interaction between the presentation modality and the probe type variables also was not statistically significant [$F(3,280) = 0.12$]. The only statistically significant effect was that of presentation modality [$F(3,280) = 5.00, MS_e = 6,343, R_p^2 = .05$]. Planned orthogonal contrasts showed that (1) the auditory-auditory condition differed from all other conditions [$t(280) = -3.73, R_p^2 = .05$], (2) the visual-visual condition did not differ from the

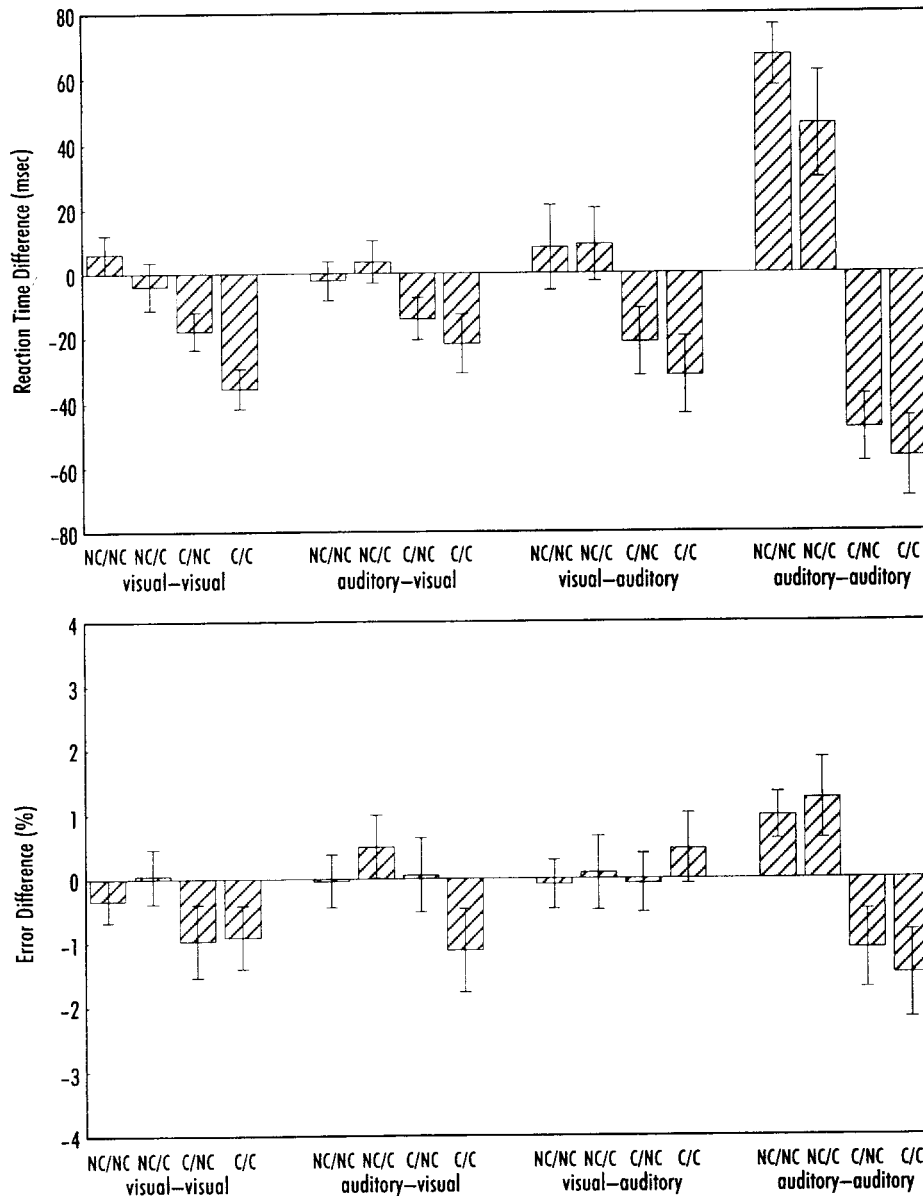


Figure 2. Mean probe reaction time and error percentage differences between control and ignored repetition trials (negative values indicate negative priming) as a function of presentation condition (visual-visual, auditory-visual, visual-auditory, and auditory-auditory; between subjects) and trial type (NC represents nonconflict primes/probes, C represents conflict primes/probes). The error bars depict the standard errors of the means.

two cross-modal presentation conditions [$t(280) = -0.54$], and (3) the visual-auditory condition did not differ from the auditory-visual condition [$t(280) = -0.89$].

DISCUSSION

To our knowledge, the present experiment is the first to demonstrate negative priming, using the same experimental task, with visual and auditory stimuli and also across these two modalities. This demonstration is con-

sonant with the finding of auditory-to-visual negative priming by Driver and Baylis (1993). In addition, the present data show that auditory-to-visual and visual-to-auditory negative priming is fairly symmetrical. Two mechanisms may account for these cross-modal effects. First, the mental representations on which the supposed mechanisms operate may include abstract, amodal stimulus information. Second, the presentation of a stimulus in one modality may automatically activate features in other modalities. Both mechanisms may operate jointly. In contrast, the present cross-modal negative priming ef-

fects cannot be attributed to processes operating on response-related information, because the response category of an ignored prime was always the same on a particular ignored repetition trial and its matching control trial.

Negative priming was observed only after conflict, but not after nonconflict, primes. Note, however, that prime and probe responses necessarily changed in the former case (for both control trials and their parallel ignored repetition trials) but remained the same in the latter. Although this unavoidable confound renders the interpretation of the present finding ambiguous in principle, we believe that the conflict/nonconflict nature of the primes, and not the prime-probe response alternation/repetition, determined the observed pattern of performance. If this position is accepted, the observed data pattern is most easily explained within the distractor inhibition (Tipper, 1985; Tipper & Cranston, 1985) and the episodic retrieval accounts of negative priming (Neill & Valdes, 1992; Neill, Valdes, & Terry, 1995; Neill, Valdes, Terry, & Gorfein, 1992). Within the inhibition account, a previously ignored stimulus is inhibited, which slows down the response when the stimulus is subsequently presented as the probe target. It could be assumed that nonconflict prime distractors do not interfere with the prime reaction, so that they need not be inhibited. Within the episodic retrieval account, negative priming may be caused by the probe target's cuing the retrieval of the perceptually similar prime display in which the distractor representation contains the information that no response was (to be) made to that stimulus. This nonresponse information conflicts with the requirement to react to the prime target. Nonconflict prime distractors may not receive a nonresponse tag, so that there exists no conflict with the probe response requirement.

The situation is different for the temporal discrimination account (Milliken, Joordens, Merikle, & Scifert, 1998). Within this framework, negative priming is not the result of the prior act of "selecting against" a distractor. Instead, the critical processes occur during probe response generation. Two classes of processes may be involved. First, if the probe target can be classified as old, automatic processes are likely to determine the response, in that the prior action is simply retrieved and executed. This corresponds to attended repetition trials, which usually result in positive priming effects. Second, a probe target classified as new receives normal perceptual analysis before response generation, which takes more time than simply retrieving a recent response. This corresponds to control trials in which the probe target is unrelated to the prime stimuli. Third, on ignored repetition trials, the target has been part of the prime display but has not been fully attended. It is somewhat familiar, so that it cannot be quickly categorized as new, but it is not familiar enough to be immediately classified as old. Negative priming is the extra time taken by the system "hanging" while trying to decide whether a stimulus is old or new. In order to explain the lack of negative priming on nonconflict trials, the temporal discrimination account

must be extended. For instance, it could be assumed that nonconflict primes are processed too superficially, so that they are functionally equivalent to novel stimuli. Alternatively, one could assume that the categorical relationship between the prime and the probe target on nonconflict trials makes the probe target appear more familiar on some trials, so that the speed-up in reaction time on those trials "neutralizes" the cost of trials on which the system "hangs," as described above.

The positive priming on nonconflict prime trials in the auditory-auditory condition was unexpected. We can only speculate about the underlying mechanisms. It seems possible that the acoustic aspects of auditory distractor representations are maintained more efficiently in a "long auditory store" (see Cowan, 1984) than the perceptual aspects of the representations of visual distractors are maintained in visual short-term memory. The additional facilitation would thus depend on whether the acoustic aspects of the auditory stimuli play a role on a particular trial, which, in the present experimental situation, was the case only in the auditory-auditory condition. Within the inhibition model, one could assume that no or only a small amount of inhibition may be allocated to the auditory nonconflict distractor representations, so that there is nothing or, at least, not much to counteract the strong facilitatory effects when the still-activated representation of the auditory distractor is reprocessed on ignored repetition trials (see Houghton & Tipper, 1994). Within the episodic retrieval model, the faster responses to the previous auditory nonconflict distractor could be explained by assuming that the acoustic features of an auditory probe may be more efficient retrieval cues for an auditory prime from the "long auditory store," making this retrieval more likely on auditory-auditory trials.

At any rate, the present data may partially explain the absence of (published) negative priming research in the auditory domain. In trials with nonconflict probes in the auditory-auditory condition, we observed positive priming, rather than no priming, as in the other presentation conditions. Had we not distinguished between conflict and nonconflict prime trials, we would not have observed any priming at all in the auditory-auditory condition: The effect was only 2 msec and in the wrong direction. In contrast, the same overall difference was -13 msec for the visual-visual condition, and this difference is statistically significant [$F(1,70) = 15.59, MS_e = 2,947$]. Thus, ignoring the conflict-nonconflict prime distinction would have led to the finding of significant negative priming in the visual-visual condition, but it would have led us to erroneously accept the null hypothesis of no negative priming in the auditory-auditory condition.

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NOTE

1. The power calculations were conducted using the G•Power program (Erdfelder, Faul, & Buchner, 1996).

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