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Episodic retrieval processes take place automatically in auditory negative priming

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Episodic retrieval processes involved in negative priming have been argued to be susceptible to the proportion of attended repetition trials. The more trials with the same prime and probe response, the more beneficial should it be to retrieve the prime episode, particularly its response. Retrieval of the prime episode, however, is task-inappropriate for ignored repetition trials, leading to negative priming. Correspondingly, visual negative priming increases with the proportion of attended repetition trials. We tested whether the same is true for the auditory modality. Three attended repetition proportion groups (0–25–50%) showed the same amount of negative priming. All groups committed more prime response errors in ignored repetition than in control trials, implying that prime response retrieval took place. Thus, retrieval processes in auditory negative priming appear to be automatic and cannot be influenced as easily as in the visual domain. In Experiment 2, the proportion of ignored repetition trials was manipulated (25–50–75%) to test whether auditory negative priming can be strategically manipulated at all. Similar to the visual modality negative priming was reduced with increasing proportion of ignored repetition trials. Differences between visual and auditory short-term memory are discussed to account for the results.

Keywords: Auditory modality; Episodic retrieval; Negative priming.

The negative priming effect denotes slowed-down responses to a stimulus that had to be ignored in a previous prime display compared with responses to a stimulus that did not occur in the previous prime display. The vast majority of negative priming evidence comes from the visual modality but the effect has also been demonstrated in the auditory domain (Banks, Roberts, & Ciranni, 1995; Mayr & Buchner, 2007; Mondor, Leboe, & Leboe, 2005). According to the distractor inhibition model (Houghton & Tipper,

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1994; Tipper, 1985), this effect is caused by an inhibition of distracting information during the prime. Inhibition is assumed to persist so that the reacting to the inhibited item is subsequently hampered. The episodic retrieval model assumes that in ignored repetition trials the probe target serves as a retrieval cue to the recent prime episode. The model predicts negative priming due to retrieval of a do-not-respond tag attached to the previously ignored stimulus (Neill & Valdes, 1992) or due to inappropriate retrieval of prime response information (Mayr & Buchner, 2006; Rothermund, Wentura, & de Houwer, 2005). Either way, the retrieved information conflicts with the probe trial requirement to respond to the same stimulus when it becomes the target. Resolving this conflict takes time. As the episodic retrieval model of negative priming is a logical extension of Logan's (1988) instance theory of automaticity, the memory retrieval mechanism in its original variant is conceived to take place obligatorily as the unavoidable consequence of attending to the probe. However, such automatic retrieval attempts are not necessarily successful, as they do not always result in successful prime episode retrieval. Nevertheless, successful prime retrieval is essential for negative priming to occur.

Within recent years, considerable evidence has accrued that supports the validity of the episodic retrieval model in the visual as well as the auditory modality (for a review, see Mayr & Buchner, 2007). For example, there is evidence for both modalities that participants make more errors with the former prime response to the probes of ignored repetition trials compared to control trials (Mayr & Buchner, 2006). This finding can only be explained by the prime–response retrieval variant of the episodic retrieval model. Similarly, Rothermund et al. (2005) showed that negative priming depends on a response change between prime and probe presentations. In contrast, if prime and probe responses are identical, the typical slowdown of ignored repetition trials inverts into a positive priming effect. This dependency of negative priming on a prime–probe response change can be explained by a memory mechanism retrieving prime response information that is probe-response incompatible in the response change case, but probe-response compatible in the no change case. In sum, there is reason to assume that episodic retrieval processes are involved in the phenomenon of negative priming, the potential coinvolvement of other mechanisms—such as inhibition processes—notwithstanding.

In some previous studies, the rationale of demonstrating memory retrieval processes in negative priming tasks has been to show that the size of the effect is influenced by variables that usually determine memory performance. One of these variables is temporal discriminability of the to-be-retrieved memory trace at the time of retrieval (e.g., Baddeley, 1990); another one is contextual similarity between encoding and retrieval (Tulving, 1983). For the visual (Neill, Valdes, Terry, & Gorfein, 1992) as well as the auditory modality (Mayr & Buchner, 2006), temporal discriminability of the prime episode at the time of the probe presentation increases the negative priming effect. With respect to prime–probe contextual similarity, a majority of studies has demonstrated that the visual negative priming effect turns out to be larger when prime and probe presentations have a similar context (with respect to variables such as synchronicity of target–distractor onsets or stimulus–background contrast intensity) than when they differ in contextual variables (Chao & Yeh, 2008; Fox & de Fockert, 1998; Neill, 1997; Stolz & Neely, 2001; but see also Wong, 2000).

Variables such as temporal discriminability and prime–probe contextual similarity presumably restrict the probability of successful retrieval of the memory trace containing prime episode information. Successful retrieval of incompatible prime episode information, however, is a necessary precondition of negative priming. For example, trials with low temporal discriminability are those trials where the prime episode is long ago at the time of the probe presentation whereas the temporal interval between prime episode and previous preprime episodes is short. For such a situation of low temporal discriminability, the probability of successful prime episode retrieval is presumably reduced due to an increase of confusion between the long ago and temporally indistinguishable memory traces of the prime episode and earlier preprime episodes. Likewise, a decrease in prime–probe contextual similarity possibly reduces successful prime episode retrieval due to an insufficient match between cue (i.e., the probe target embedded in the probe context) and to-be-retrieved prime episode (embedded in the different context of the prime). In sum, then, automatic retrieval attempts fail either due to confusion of memory traces (temporal discriminability) or due to an ineffective retrieval cue (prime–probe contextual similarity).

Beside these memory-limiting variables already known to restrict retrieval performance in general, and prime episode retrieval in particular, further context variables have been proposed to influence episodic retrieval processes involved in negative priming in a somewhat more strategic[1] mode of operation. Kane, May, Hasher, Rahhal, and Stoltzfus (1997) and May, Kane, and Hasher (1995) postulated that negative priming can be the result of inhibition and episodic retrieval processes, and that certain experimental context variables determine which of the two processes is active. The presence of attended repetition trials—that is, the presence of

[1] The term "strategic" does not necessarily imply that participants must be conscious of the processes taking place when they run the task. Strategy should be understood in terms of an episodic retrieval *tendency* that might be based on conscious as well as unconscious processes. Essential to the meaning of "strategy" is the fact that processes adapt to situational conditions as opposed to automatic processes that take place irrespective of whether one wants them to happen or not and regardless of the manipulation of other factors.

trials with the prime target repeated as the probe target—was argued to be one of these critical experimental context variables that induces episodic retrieval processes. For attended repetition trials, the correct prime response is also the correct probe response. Therefore, retrieval of the prime episode including prime response information was considered helpful for selecting the correct probe response. Consequently, presenting attended repetition trials in a negative priming experiment was thought to increase the strategy of retrieving the former prime episode including prime response information. However, retrieval of prime episodes is task-inappropriate in ignored repetition trials. Whatever information from the prime is retrieved—either nonresponse information attached to the prime distractor or prime response information—it conflicts with the required probe response and impedes responding. Following the rationale by Kane et al. and May et al., and thus assuming that the involvement of episodic retrieval processes is indeed subject to strategic control, the negative priming effect should be increased in an experiment including attended repetition trials in comparison to the same experiment but without the presence of attended repetition trials. What is more, increasing the proportion of attended repetition trials should enlarge the negative priming effect. Whereas temporal discriminability and prime–probe contextual similarity have a bearing on the success probability of a (supposedly) automatically functioning retrieval mechanism, the manipulation of attended repetition trial proportions as explained earlier is thought to influence whether an episodic retrieval mechanism is activated at all. Based on the expectancy of whether prime episode retrieval is useful for probe responding (i.e., in experimental contexts with many attended repetition trials) or not (i.e., in experimental contexts with few or no attended repetition trials), episodic retrieval is assumed to take place or not. Note that this idea of a strategically deployable retrieval mechanism is a deviation from the original episodic retrieval idea by Neill et al. (1992, based on Logan's theory of automaticity).

For the visual modality, a positive relation between proportion of attended repetition trials and the size of the negative priming effect has indeed been demonstrated recently by Frings and Wentura (2008). With 50% or 33% attended repetition trials in a training phase, but 33% attended repetition trials for both groups in the subsequent experimental phase, the negative priming effect was significantly larger after more (50%) than after fewer (33%) attended repetition training trials. Similarly, Lowe (1979, Exp. 2) found negative priming only in an experimental condition with a very large proportion of attended repetition trials (75%), whereas there was no effect with 25% attended repetition trials. Kane et al. (1997) reported a negative priming effect in the elderly with 40% attended repetition trials, whereas they could not find reliable negative priming in the elderly in a previous study without attended repetition trials (Kane, Hasher, Stoltzfus, Zacks, &

Connelly, 1994). In sum, then, it appears that visual negative priming seems to be positively influenced by the presence of attended repetition trials, the exception being a study by Simone, Ahrens, Foerde, and Spinetta (2006) in which the size of the negative priming effect did not depend on the proportion of attended repetition trials (0% vs. 25% vs. 50%) in a visual location priming task. The source of this discrepancy is presently unknown, but it is likely related to the differences in the processes underlying identity and location priming. For example, the visual (Milliken, Tipper, & Weaver, 1994) as well as the auditory (Mayr, Hauke, & Buchner, 2009) location priming phenomenon seem to be (partly) caused by feature mismatch processes (Park & Kanwisher, 1994), whereas identity priming is insensitive to this determining factor. Episodic retrieval processes, in return, have not been demonstrated to be involved in spatial negative priming (e.g., Mayr et al., 2009). If, however, episodic retrieval is not involved in the spatial priming phenomenon, then, a modulation of the location negative priming effect by an attended repetition proportion manipulation should not emerge.

Based on what is currently known, visual and auditory negative priming seem to be based on equivalent mechanisms (for a review, see Mayr & Buchner, 2007). Particularly, episodic retrieval of the prime response seems to be involved in both modalities, and memory-limiting variables such as temporal discriminability affect visual and auditory negative priming in the same manner (Mayr & Buchner, 2006; Neill et al., 1992). However, interexperimental comparisons of our own data suggest that episodic retrieval processes are more pronounced in the auditory than in the visual modality. Specifically, the prime response retrieval mechanism (as a subcomponent of episodic retrieval) was clearly stronger for auditory stimuli than for visual stimuli in two of our own projects that comprised parallel experiments in both modalities (Exp. 1 vs. Exp. 2 in Hauke, Mayr, Buchner, & Niedeggen, 2009; Exp. 2 vs. Exp. 3 in Mayr & Buchner, 2006). As a consequence, episodic retrieval in audition might be the more robust and powerful mechanism that is less susceptible to the modulation of experimental context variables known to influence visual negative priming. The present study was designed to investigate the similarities and possible differences between visual and auditory negative priming. Specifically, we investigated whether auditory negative priming would be as susceptible as visual negative priming to the modulation of an experimental context variable that is assumed to induce episodic retrieval processes. In particular, in Experiment 1 we tested whether the increase of attended repetition trials increases the probability of episodic retrieval processes, which, in turn, should increase the size of the negative priming effect. Three groups of participants in an auditory four-alternative forced choice identification task received different proportions of attended repetition trials (0% vs. 25% vs. 50%). If episodic retrieval processes in auditory negative priming were susceptible to this manipulation, then the auditory negative priming effect should increase with increasing proportions of attended repetition trials as in the visual modality (Frings & Wentura, 2008). Alternatively, if episodic retrieval processes were automatic (and were limited by only memory-restricting variables such as temporal discriminability and prime–probe contextual similarity), then the negative priming effect should be unaffected by the proportion manipulation of attended repetition trials. In order to maximise the chance of finding an influence of attended repetition proportion on negative priming we (1) varied the proportion of attended repetition trials across a large range of values and (2) integrated the manipulation of attended repetition trials into the experimental test phase, but not the training phase.

EXPERIMENT 1

Method

Participants. Participants were 171 adults, 46 of whom were male. They ranged in age from 18 to 40 years ($M = 24$). All participants were either paid for their participation or received partial course credit. The data of seven further participants had to be discarded: Six data sets were eliminated due to excessive error rates ($> .50$) in at least one experimental condition. One further data set was discarded because this participant responded very slowly (her average reaction times exceeded all other participants' average reaction times by more than 100 ms) and she had to repeat more than 20% of all trials due to time-outs. In the final sample, 56, 57, and 58 participants were tested in the 0%, 25%, and 50% conditions, respectively.

Materials. The stimuli were four digitised sounds (frog, piano, drum, and bell). Each sound was 300 ms long, complete with rise and decay time. The default setting was at about 70 db(A). Participants heard the sounds over earphones that were fitted with noise-insulation covers and plugged directly into an Apple iMac computer.

A 20 ms metronome click indicated the ear (left or right) at which the to-be-attended sound would be presented. Participants reacted to the attended sound by pressing the response key assigned to the sound. Response keys were the four keys "M", "N", "B", and "V" on the computer keyboard. For each participant, the sounds were randomly assigned to the keys. For each participant, the experimenter labelled the keys with small stickers of the colour associated with the object in the instructions (green for frog, black for piano, blue for drum, and red for bell). Participants were instructed to press the four keys with the index, middle, ring, and little finger of their dominant hand.

Each experimental trial consisted of a prime and a probe display. Each display consisted of a target presented to one ear and a simultaneously presented distractor at the other ear. The attended ear always changed between the prime and the probe display. Trial configuration of the 25% attended repetition proportion condition is described first, followed by the 50% and the 0% condition. The 25% condition is the standard condition as used in Experiment 2 of Mayr and Buchner (2006) and in Mayr, Buchner, and Dentale (2009) for which significant negative priming as well as evidence of prime–response retrieval has been found.

Ignored repetition trials were constructed by randomly selecting three of the four different stimuli as prime and probe targets and distractors with the restriction that the ignored prime had to be identical to the attended probe (left-most column of Table 1). Next, parallel control trials were constructed by replacing the ignored prime with the remaining stimulus (piano replaced by bell in the example displayed in Table 1). Attended repetition trials were constructed by randomly selecting three of the four different types of stimuli as prime and probe targets and distractors with the restriction that the attended prime had to be identical to the attended probe. Attended repetition control trials were constructed by replacing, in the attended repetition trials, the attended prime with the remaining stimulus. Also note that the construction principle of control trials and attended repetition control trials was the same, so that both conditions were equivalent. Note that an ignored repetition trial always shared its control trial with an attended repetition filler trial (see Table 1 for an example). Had we used the entire set of trials that can be generated by the algorithm just described, then every control trial would have occurred twice, possibly resulting in an unwanted response speed-up at the second presentation of each control trial (which would artificially increase the negative priming effect in reaction times). In order to avoid this confound, ignored and attended repetition trials were systematically assigned to Set 1 or Set 2 with three restrictions: First, identical control trials had to belong to different sets. Second, within each trial type, the frequencies of the different sounds had to be identical. Third, the frequencies of the combinations of attended and ignored sounds, both within the prime and within the probe pairs, had to be equal for the different trial types. Sets 1 and 2 were completely parallel with respect to the second and the third restriction. For each set, the required prime response did not predict the required probe response. Participants were randomly assigned to Set 1 or 2.

Each set included 12 different trials of each of the four trials types (ignored repetition, control, attended repetition, attended repetition control, 48 trials overall). Each trial in a set was duplicated, once to be presented with the attended prime on the left and the attended probe on the right side, and once to be presented with the opposite arrangement. A set was presented three times,

TABLE 1
Examples of stimulus configurations and required responses (in italics)

	Ignored repetition		*Ignored repetition control*		*Attended repetition*		*Attended repetition control*	
	Attended ear	*Ignored ear*	*Attended ear*	*Ignored ear*	*Attended ear*	*Ignored ear*	*Attended ear*	*Ignored ear*
Prime	frog	piano	frog	bell	piano	bell	frog	bell
	frog		*frog*		*piano*		*frog*	
Probe	piano	drum	piano	drum	piano	drum	piano	drum
	piano		*piano*		*piano*		*piano*	

resulting in 288 experimental trials which were presented in a random sequence.

In the 50% attended repetition proportion condition, the 25% attended repetition control trials were replaced by a duplicate set of the 25% attended repetition trials, resulting in 25% ignored repetition, 25% control, and 50% attended repetition trials. In the 0% attended repetition proportion condition, the 25% attended repetition trials were replaced by a duplicate set of the 25% attended repetition control trials, resulting in 25% ignored repetition, 25% control, and 50% attended repetition control trials, that is, 75% trials without any stimulus repetition. Note that the trial type conditions relevant for hypothesis testing—that is, ignored repetition and control trials—were identical in all three attended repetition proportion conditions.

Procedure. Before the experiment started, participants were given opportunity to adjust the loudness to a comfortable level that nevertheless enabled them to hear the click and to differentiate the sounds when simultaneously played. First, participants were familiarised with the sound stimuli. Next, participants heard and reacted to pairs of sounds. Preceding the sound pair, the metronome click indicated the randomly selected ear at which the to-be-attended sound would be presented. Following a 500 ms click–target interval, a randomly selected target sound was presented at that ear and a to-be-ignored distractor was presented simultaneously to the other ear. Participants reacted to the target sound by quickly pressing the corresponding key. They were given feedback about the correctness of each reaction after which they initiated the next trial. The sound-response association was presented in the upper half of the display during the first 25 training trials. Participants entered the experiment proper when 60% of the preceding 50 training trials had been responded correctly. Almost all participants mastered this criterion within the first 50 trials. Participants who did not reach this criterion within 150 trials were given a choice to quit the experiment or to start again with the training. Participants were neither informed about the different trial types nor the proportion of attended repetition trials in the subsequent experiment trials.

Each of the 288 experimental trials began with the metronome click, followed by a 500 ms cue–target interval and the prime pair of sounds. After the prime reaction, a response–stimulus interval of 500 ms preceded the click that cued the to-be-attended probe. The probe click (presented to the opposite of the prime target presentation side) was followed by a 500 ms cue–target interval, after which the probe pair of sounds was presented. After each prime–probe pair of trials participants were given feedback about the correctness of their prime and probe reactions, followed by a 1800 ms intertrial interval. Prime or probe reactions faster than 100 ms, prime responses slower than 3000 ms, and probe responses slower than 2000 ms were counted as invalid and the entire trial was repeated after the last experimental trial. There was no significant difference in the number of repeated trials between the three attended repetition proportion groups (summed over all trial type conditions, there were on average 4.3 vs. 3.9 vs. 5.2. repeated trials, in the 0%, the 25%, and the 50% proportion conditions, respectively), $F(2, 168) = 1.38$, $p = .26$, $\eta^2 = .02$. After every tenth trial, participants received a summary feedback about both their average reaction time and their error percentage. After the final trial, all participants were informed about the purpose of the experiment.

Design. The experiment comprised a 2×3 mixed design with trial type (ignored repetition vs. control) as within-subject variable and attended repetition proportion (0% vs. 25% vs. 50%) as between-subjects variable. The primary dependent variable was participants' average reaction time, but error rates were also analysed.

The difference of the negative priming effect (ignored repetition – control) between the three levels of the attended repetition proportion variable was relevant for our a priori power considerations. In order to detect a small to medium interaction effect (as defined by Cohen, 1988), that is, an effect of size $f = 0.15$, given a population correlation of $\rho = .5$ between the reaction time variables ignored repetition and control, and desired levels of $\alpha = \beta = .05$, data had to be collected from a sample of at least $N = 177$ participants (Faul, Erdfelder, Lang, & Buchner, 2007). We were able to collect data from $N = 171$ participants so that the power was negligibly smaller (.946). The level of alpha was maintained at .05 for all statistical decisions.

In all experiments reported in this paper, a multivariate approach was used for all within-subject comparisons. Statistical significance was based on Pillai's trace test criterion. In our application, all multivariate test criteria correspond to the same (exact) F-statistic, which is reported.

Results

Reaction times and overall error rates. Probe reaction times were evaluated only for trials in which prime and probe responses were correct.[2] The means of

[2] For control reasons, we ran a 2×3 MANOVA of the reaction time prime data with trial type (ignored repetition vs. control) as within-subject variable and attended repetition proportion as between-subjects variable (0% vs. 25% vs. 50%) to test whether prime processing was equivalent across groups. Prime response times did neither differ across groups nor between the trial type conditions, as there was neither a main effect of group, $F(2, 168) = 0.70$, $p = .50$, $\eta^2 = .01$, nor a main effect of trial type, $F(1, 168) = 0.02$, $p = .90$, $\eta^2 < .01$, nor an interaction between both variables, $F(2, 168) = 0.07$, $p = .93$, $\eta^2 < .01$. The same was true for the prime error rates, as there was neither a main effect of group, $F(2, 168) = 0.65$, $p = .53$, $\eta^2 = .01$, nor a main effect of trial type, $F(1, 168) = 1.52$, $p = .22$, $\eta^2 = .01$, nor an interaction between both variables, $F(2, 168) = 0.07$, $p = .93$, $\eta^2 < .01$. On average, participants responded 940 ms after prime stimulus onset and committed approximately 6.0% prime errors.

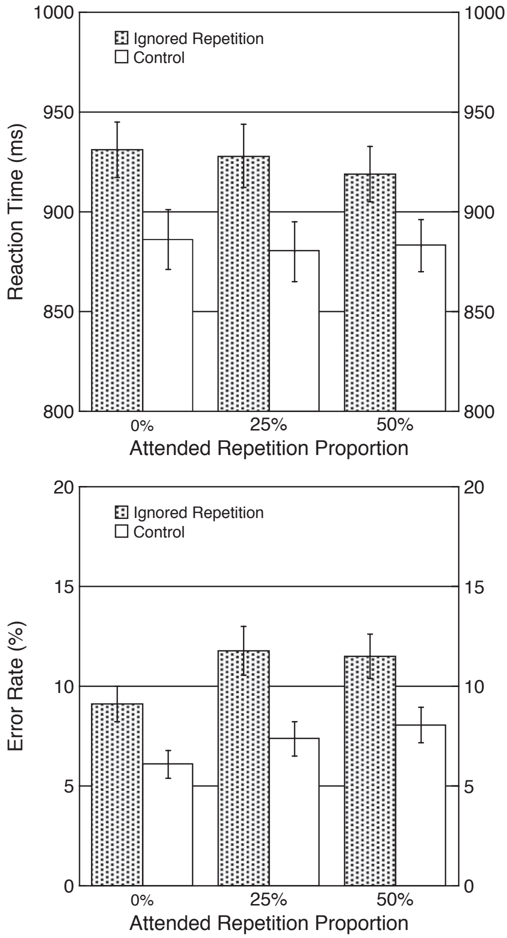

Figure 1. Mean reaction times (upper panel) and error rates (lower panel) as a function of trial type (ignored repetition vs. control) and attended repetition proportion in Experiment 1. The error bars depict the standard errors of the means.

participants' average reaction times and error rates are presented in Figure 1. The upper panel shows that the mean reactions were slower in the ignored repetition condition than in the control condition. The manipulation of attended repetition trial proportion did not modulate reaction times. Most interestingly and contrary to what has been found in the visual modality, the negative priming effect was not modulated by the proportion of attended repetition trials.

A 2×3 MANOVA of the reaction time data with trial type (ignored repetition vs. control) as within-subject variable and attended repetition proportion as between-subjects variable (0% vs. 25% vs. 50%) showed a significant main effect of trial type, $F(1, 168) = 93.30$, $p < .01$, $\eta^2 = .36$. The main effect of attended repetition proportion was not significant, $F(2, 168) = 0.07$, $p = .93$, $\eta^2 < .01$, nor was the interaction between both variables, $F(2, 168) = 0.62$, $p = .54$, $\eta^2 = .01$. Negative priming was significant at all three levels of the attended repetition proportion variable, as is shown by follow-up tests using the Bonferroni-Holm method (Holm, 1979) of protecting against α-error accumulation, $t(55) = 6.42$, $p < .01$, $d_z = 0.86$ for the 0% condition, $t(56) = 5.53$, $p < .01$, $d_z = 0.73$ for the 25% condition, and $t(57) = 4.92$, $p < .01$, $d_z = 0.65$ for the 50% condition.

An analogous analysis of the error data (lower panel of Figure 1) revealed a significant main effect of trial type, $F(1, 168) = 90.31$, $p < .01$, $\eta^2 = .35$, but neither a main effect of attended repetition proportion, $F(2, 168) = 1.73$, $p = .18$, $\eta^2 = .02$, nor an interaction between these variables, $F(2, 168) = 1.16$, $p = .32$, $\eta^2 = .01$. Again, negative priming was significant at all three levels of the attended repetition proportion variable, as is shown by follow-up tests, $t(55) = 5.95$, $p < .01$, $d_z = 0.79$ for the 0% condition, $t(56) = 6.57$, $p < .01$, $d_z = 0.87$ for the 25% condition, and $t(57) = 4.49$, $p < .01$, $d_z = 0.59$ for the 50% condition.

Participants had to learn the trial proportions in the beginning of the experimental phase before the proportion manipulation could make any difference in trial processing between groups (the training phase consisted of single trials only for all three proportion groups). As a consequence, the attended repetition proportion manipulation should have a stronger impact on trials in the second half than in the first half of the experiment. We therefore analysed the negative priming effects for experimental trials of the second test half separately. A 2 × 3 MANOVA of the reaction time data with trial type as within-subject variable and attended repetition proportion as between-subjects variable showed the same pattern of results as the overall analysis. There was a significant main effect of trial type, $F(1, 168) = 43.66$, $p < .01$, $\eta^2 = .21$, but neither a main effect of attended repetition proportion, $F(2, 168) = 0.12$, $p = .89$, $\eta^2 < .01$, nor an interaction between both variables, $F(2, 168) = 1.58$, $p = .21$, $\eta^2 = .02$. An analogous analysis of the error data for trials of the second test half revealed a significant main effect of trial type, $F(1, 168) = 40.14$, $p < .01$, $\eta^2 = .19$, but neither a main effect of attended repetition proportion, $F(2, 168) = 1.09$, $p = .34$, $\eta^2 = .01$, nor an interaction between these variables, $F(2, 168) = 0.28$, $p = .76$, $\eta^2 < .01$.

We further analysed whether the size of the repetition priming effect in attended repetition trials versus control trials was modulated by the proportion of attended repetition trials (50% vs. 25% group). The implications of these findings will be discussed in the Discussion section. The means of participants' average reaction times and error rates are presented in Figure 2. Figure 2 (upper panel) shows that the reaction times were reduced

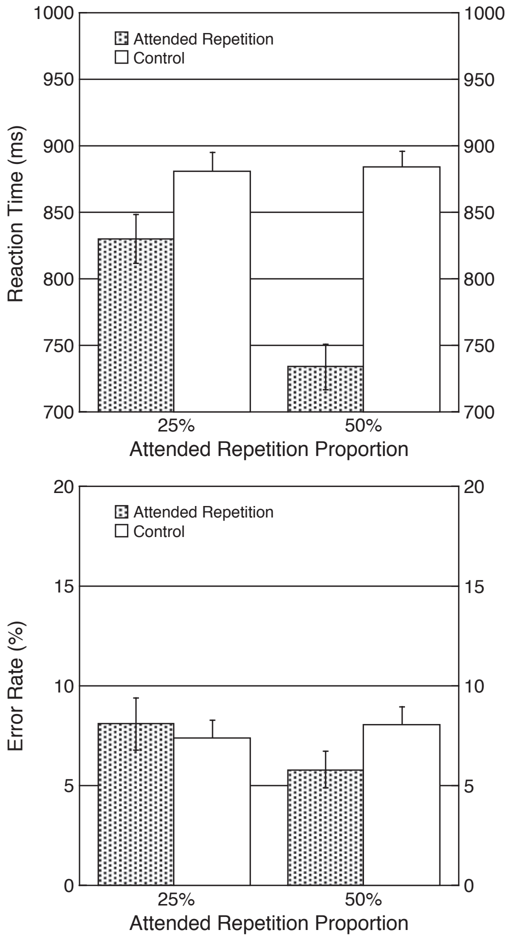

Figure 2. Mean reaction times (upper panel) and error rates (lower panel) as a function of trial type (attended repetition vs. control) and attended repetition proportion in Experiment 1. The error bars depict the standard errors of the means.

in attended repetition trials in comparison to control trials. Most interestingly, the repetition priming effect was modulated by the proportion of attended repetition trials. Whereas there was a considerable reduction in reaction times for the attended repetition relative to the control condition in the 25% group, this difference was much larger in the 50% group.

A 2×2 MANOVA of the reaction time data with trial type (attended repetition vs. control) as within-subject variable and attended repetition proportion as between-subjects variable (25% vs. 50%) showed a significant main effect of trial type, $F(1, 113) = 157.55$, $p < .01$, $\eta^2 = .58$, a main effect of attended repetition proportion, $F(1, 113) = 4.83$, $p = .03$, $\eta^2 = .04$, as well as an interaction between both variables, $F(1, 113) = 39.08$, $p < .01$, $\eta^2 = .26$. Repetition priming was significant at both levels of the attended repetition proportion variable, as is shown by follow-up tests using the Bonferroni-Holm method of protecting against α-error accumulation, $t(56) = 4.46$, $p < .01$, $d_z = 0.59$ for the 25% condition, and $t(57) = 13.29$, $p < .01$, $d_z = 1.75$ for the 50% condition. An analogous analysis of the error data revealed neither a significant main effect of trial type, $F(1, 113) = 2.08$, $p = .15$, $\eta^2 = .02$, nor of attended repetition proportion, $F(1, 113) = 0.40$, $p = .53$, $\eta^2 < .01$, but a significant interaction between these variables, $F(1, 113) = 8.69$, $p < .01$, $\eta^2 = .07$. Positive priming was significant for the 50% group, $t(57) = 4.08$, $p < .01$, $d_z = 0.54$, but not for the 25% group, $t(56) = 0.89$, $p = .19$ (one-sided testing), $d_z = 0.12$.

Evidence of episodic retrieval processes. Episodic retrieval of prime episode information is expected be stronger in ignored repetition than in control trials because only the former trials comprise a stimulus repetition from prime (distractor) to probe (target) that may function as a retrieval cue to the prime episode. One aspect of the prime episode is the prime response. Therefore, it is expected that prime response information is retrieved with a larger probability in ignored repetition trials than in control trials. As a consequence, the probability of erroneous responses with the former prime response should be increased in ignored repetition trials compared to control trials.

We analysed the error frequency data displayed in Table 2 using the multinomial model introduced by Mayr and Buchner (2006) in order to test whether episodic retrieval processes in the form of prime–response retrieval processes were involved in the negative priming effects observed in this experiment. The underlying multinomial model represents the processing stages presumably involved in generating a probe response in a four-alternative forced choice task for both the ignored repetition and the control condition. The model assumes that participants *c*orrectly *i*dentify and respond to the probe target with probability *ci*. Errors (with probability 1 – *ci*) might have various causes. Participants might experience a *p*robe *s*timulus *c*onfusion in that they confuse target and distractor and respond with the probe distractor with conditional probability *psc*. If probe stimulus confusion does not dominate responding (with probability 1 – *psc*), then, with probability *prr*, *p*rime *r*esponse *r*etrieval may occur and lead to incorrect prime responses. If prime–response retrieval occurred, then the probability of retrieving a prime response in the ignored repetition condition, prr_{IR}, is expected to be larger than prr_C, the same probability in the control condition. Thus, if $prr_{IR} > prr_C$ and if, in addition, the goodness-of-fit test of the restricted model assuming $prr_{IR} = prr_C$ leads to a significant misfit,

TABLE 2
Accumulated absolute frequencies of correct probe responses and of the different types of probe errors as a function of trial type (ignored repetition vs. control) and attended repetition proportion (0% vs. 25% vs. 50%) in Experiment 1

	Attended repetition proportion					
	0%		*25%*		*50%*	
	Ignored repetition	*Control*	*Ignored repetition*	*Control*	*Ignored repetition*	*Control*
Correct probe target responses	3480	3584	3422	3569	3473	3594
Incorrect probe distractor responses	266	185	314	228	277	235
Incorrect prime target responses	35	2	81	13	114	17
Other incorrect responses*	38	37	44	30	46	52

*Ignored repetition trials: Incorrect responses using the key that was assigned to the nonpresented stimulus. Control trials: Incorrect prime distractor responses.

then this is evidence in favour of the assumption that prime–response retrieval occurs and contributes to the negative priming effect.

For each of the three attended repetition proportion groups, the multinomial model just described was fitted to the frequency data displayed in Table 2. For each group the unrestricted model fitted the data perfectly. The estimates of the prime–response retrieval parameters prr_{IR} and prr_{C} are illustrated in Figure 3. In a next step, we tested the goodness-of-fit of the model with the restriction that $prr_{IR} = prr_{C}$. This was done for each proportion group. The restricted model did not fit the data in the 0%, the 25%, and the 50% group with $G^2(1) = 25.26$, $p < .01$,[3] $w = .058$, $G^2(1) = 15.64$, $p < .01$, $w = .045$, and $G^2(1) = 43.67$, $p < .01$, $w = .075$, respectively. Thus, there was significant prime response retrieval in all three conditions.

In order to test whether prime–response retrieval processes as one component of episodic retrieval processes increase with increasing proportions of attended repetition trials, a comparison of the prime–response retrieval effect—the difference between the prr_{IR} and the prr_{C} parameter—between the 0%, the 25%, and the 50% attended repetition proportion group is necessary. However, a direct test of such an interaction hypothesis (Trial type × Attended repetition proportion) is not possible in a multinomial

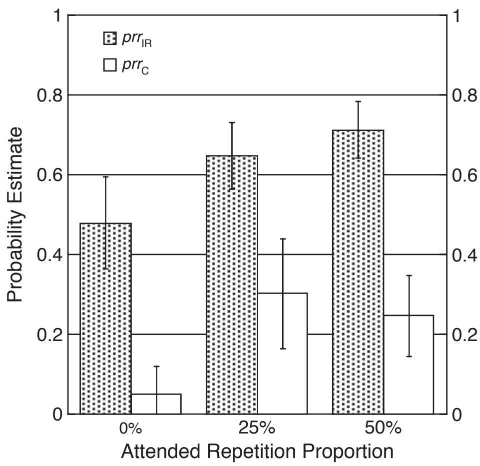

Figure 3. Probability estimates for the model parameters representing the probability of prime–response retrieval as a function of trial type (ignored repetition vs. control) and attended repetition proportion in Experiment 1. The error bars depict the 95% confidence intervals.

[3] The log-likelihood goodness-of-fit statistic G^2 is asymptotically χ^2-distributed with the degrees of freedom indicated in parentheses (see Hu & Batchelder, 1994, for details). The goodness-of-fit test was conducted using the AppleTree program (see Rothkegel, 1999).

model. Instead, this interaction effect can be assessed only indirectly by comparing the estimated effect sizes of the misfits of the restricted model, that is, by comparing *w*. Accordingly, we compared the effect sizes of the prime–response retrieval effects between the 0%, the 25%, and the 50% group, that is, $w = .058$, $w = .045$, and, $w = .075$, respectively. By and large, the effect sizes were in the same order of magnitude. What is more, there was no monotonic increase of effect sizes from the 0% to the 50% group. Overall, these data show a general involvement of prime–response retrieval processes in the negative priming effect found in Experiment 1. Additionally, the data show no modulation of negative priming due to an attended repetition proportion manipulation. The latter is parallel to the results obtained for the overall reaction time and error data.

Discussion

Experiment 1 was planned to test whether episodic retrieval processes active in auditory negative priming are susceptible to strategic manipulation. This was carried out by manipulating the proportion of attended repetition trials, a manipulation that has been shown to affect the size of the negative priming effect in the visual modality (e.g., Frings & Wentura, 2008). We found a negative priming effect in all three attended repetition proportion groups. However, we did not find any modulation of the auditory negative priming effect, neither for reaction times nor for error rates. If anything, the negative priming effect was somewhat smaller in the 50% attended repetition proportion group compared to the 25% and the 0% groups. Note that we maximised the chance of finding an influence of attended repetition proportion on negative priming by varying the proportion of attended repetition trials across a very large range of values (0% vs. 25% vs. 50%)—by far a larger range than in the visual study by Frings and Wentura (2008) (33% vs. 50%)—and nevertheless failed to find a modulatory effect.

Taking into account that contingency learning needs some time to develop, we reanalysed trials only from the second half of the experiment. The results did not change the conclusions from the overall analysis. In clear contrast to the visual modality (e.g., Frings & Wentura, 2008), auditory negative priming does not seem to be susceptible to an attended repetition proportion manipulation, not even in the second test half. Note that our experiment included a rather large number of trials, that is, 288 overall, 144 per test half. Thus, there should have been enough time to learn the trial contingencies, particularly when calculating negative priming effects only from trials of the second test half. In contrast, Frings and Wentura's (2008) training phase for which proportion manipulation was induced comprised only 80 trials; nevertheless they found proportion effects on negative priming for the subsequent experimental test trials. Therefore, the absence of a modulation of proportion effects in the present experiment cannot be attributed to a short and therefore ineffective learning phase. What is more, the proportion manipulation in our experiment was implemented throughout the whole experimental test phase and should have comprised local trial-by-trial effects as well as global context effects. Trial-by-trial effects should come into effect as an immediate consequence of an attended repetition trial. Following an attended repetition trial, participants might especially focus on target repetitions and might expect a repetition of the attended stimulus in the next trial again. As a consequence, they would be strongly affected when an ignored repetition trial instead of an attended repetition trial followed, and in turn, the negative priming effect would be particularly large. Such immediate local influences from the previous trial (similar to trial-by-trial effects that have been reported in related paradigms such as the Simon paradigm; see, e.g., Wühr & Ansorge, 2005) conceptually differ from global context effects. Global effects correspond to a learning process during the course of a larger number of trials. Participants might learn that reliance on retrieval of the former prime episode and prime response would be more often beneficial than detrimental to correct responding. As a consequence, participants would develop a general strategy to retrieve the former prime response. Neither trial-by-trial nor context effects were sensitive to attended repetition proportion manipulations in Experiment 1, whereas Frings and Wentura (2008) demonstrated that global context effects alone were able to modulate the visual negative priming effect. In sum, the pattern of results allows for the conclusion that auditory negative priming mechanisms differ from visual negative priming mechanisms in that the former but not the latter are immune to contingencies included in the trial set-up.

The model-based analysis of the error frequency data revealed that participants in all groups made more probe errors with the former prime response in ignored repetition trials compared to control trials. What is more, this increase in specific probe response errors with the former prime response in ignored repetition trials was of comparable magnitude in all three proportion groups. This implies that comparable prime–response retrieval processes were involved in all three attended repetition groups, even in the 0% attended repetition proportion group for which—from a strategic point of view—prime episodic retrieval was of no use. In other words, there was evidence of episodic retrieval processes although prime retrieval could only be detrimental to responding (as in the case of ignored repetition trials) but never beneficial (since there were no attended repetition trials in the 0% group). This aspect of the data points to a strong automatic mechanism that cannot be modified by strategic processes.

In Experiment 1, we also analysed repetition effects in response to the attended repetition trials in comparison to control trials. Typically, the immediate repetition of a stimulus and its associated response results in a reaction time benefit. Repetition effects or positive priming effects have been reported for auditory negative priming tasks including attended repetition trials that were very similar to the task used here (e.g., Buchner & Steffens, 2001), but repetition effects are a far more general and well-established phenomenon (e.g., Bertelson, 1961, 1965; Pashler & Baylis, 1991). As expected, we found a speed-up in responding to attended repetition trials in the 50% as well as the 25% attended repetition proportion group of Experiment 1. In clear contrast to our negative priming results, however, the size of the repetition effect was strongly modulated by the proportion of attended repetition trials. The repetition effect was much larger in the 50% group ($d_z = 1.75$) than in the 25% group ($d_z = 0.59$). This leads to the question why the repetition effect found in Experiment 1 was modulated by the attended repetition proportion manipulation whereas there was no modulation of the negative priming effect. Obviously, the positive priming or repetition effect is under control of a different mechanism than the negative priming effect. Since there is a repetition of the stimulus as well as a repetition of the response in attended repetition trials, there are per se two potential causes of the reaction time benefit in attended repetition trials. However, research by Bertelson (e.g., 1961; e.g., 1965) as well as by Pashler and Baylis (1991) has revealed that repetition effects are primarily located at the level of response mechanisms. Based on a series of experiments, Pashler and Baylis concluded that repetition effects are due to transient short-cuts in response selection for immediately repeated stimuli but not the result of speeded perceptual processing. Presumably, a direct translation from an early stimulus representation all the way to a fairly specific response is established, thereby omitting the detailed processing steps of stimulus analysis and response selection. Obviously then, the facilitatory effect of attended repetition trials is due to a response short-cut that has little or nothing to do with a memory-based episodic retrieval mechanism involved in the negative priming phenomenon.

If short-cutting the response selection stage makes up the response time benefit of attended repetition trials (Pashler & Baylis, 1991), then this short-cutting seems to be speeded up when the amount of attended repetition trials is increased, as from the 25% to the 50% group. We assume that the increase of attended repetition trials strengthens participants' tendency to start response initiation based on increasingly less perceptual evidence. Whereas participants might be more cautious in repeating a response if there are only 25% attended repetition trials overall, they might become increasingly more liberal in responding in cases where every other trial is a prime-to-probe target repetition, as in the 50% group. Becoming more liberal probably implies that response initiation starts as early as the first evidence of a repetition has been detected, such as the first milliseconds of a sound trace have been processed that equal the previous target sound.

Another explanation for the modulation of repetition priming effects could be episodic retrieval processes (in the sense of Logan's instance theory of automaticity, Logan, 1988, 1990). As already characterised at the beginning of this paper, retrieving the prime episode with the to-be-attended prime target and response should not only interfere with probe responding in ignored repetition trials but should also facilitate probe responding if the probe target and response remain the same as is the case in attended repetition trials. Then, the manipulation of attended repetition proportions should be positively related to the size of the repetition priming effect. Frings and Wentura (2008) explain the modulation of their target/response repetition effects in the visual modality as a result of episodic retrieval processes. In a similar way, Neill (1997) argued that the repetition priming effect he found was caused by the same episodic retrieval mechanism as the negative priming effect reported in the same study. Based on our findings in Experiment 1, however, we are sceptical whether the large modulation of repetition priming effects in the auditory modality—$d_z = 0.59$ and $d_z = 1.75$, for the 25% and the 50% attended repetition proportion groups, respectively—can be caused by an episodic retrieval mechanism. Given that the negative priming effect is known to depend on episodic retrieval processes (other processes notwithstanding) and given that auditory negative priming was not at all modulated by the attended repetition proportion manipulation in Experiment 1, we rather believe that the strong auditory repetition priming modulation was caused by other mechanisms, such as short-cutting the response selection stage as explained above.

Returning to the core interest of this study, that is, the negative priming phenomenon and summarising the essential findings of Experiment 1, we have to assume that episodic retrieval processes in auditory negative priming differ from those in visual negative priming in that they are not subject to strategic control but take place automatically, and are presumably only restricted to the functional limitations of the memory retrieval process itself, that is, to variables such as temporal discriminability (Mayr & Buchner, 2006) or contextual similarity between prime and probe. Obviously, episodic retrieval processes in auditory negative priming are insensitive to strategic control. With Experiment 2, we wanted to test whether the auditory negative priming phenomenon in general—not just episodic retrieval as one of its underlying mechanisms—is immune to strategic manipulation. To test this, a manipulation known to strongly modulate the visual negative priming effect was chosen in Experiment 2, that is, the manipulation of the proportion of ignored repetition trials (e.g., Frings & Wentura, 2008; Milliken, Lupianez, Debner, & Abello, 1999; Milliken & Rock, 1997).

EXPERIMENT 2

Participants were exposed to either 25%, 50%, or 75% ignored repetition trials. The proportion of ignored repetition trials is a critical variable in visual negative priming (e.g., Frings & Wentura, 2008, Exps. 2 and 3). The larger the amount of ignored repetition trials, the larger the likelihood that participants learn the contingency between ignored prime and attended probe stimuli of these trials. Knowledge of these prime–probe contingencies can be beneficial for probe responding, presumably because participants increase their attention to the prime distractor which, in turn, facilitates processing and responding to this stimulus when it becomes the subsequent probe target. Increasing the proportion of ignored repetition trials usually results in a reduction of the negative priming effect (Frings & Wentura, 2008, Exps. 2 and 3), sometimes in a reversal to positive priming (Milliken et al., 1999), at least for those participants who accurately estimated the proportions (Milliken & Rock, 1997). Experiment 2 was intended to test whether the same holds true for the auditory modality.

Method

Participants. Participants were 95 adults, 15 of whom were male. Neither of them had participated in Experiment 1. Participants ranged in age from 18 to 47 years ($M = 23.83$). All participants were either paid for their participation or received partial course credit. The data of two further participants had to be discarded: One data set was eliminated due to excessive error rates ($> .50$) in each experimental condition of interest (ignored repetition, control). One further data set was discarded because this participant responded extremely slowly and she had to repeat more than 25% of all trials due to time-outs. In the final sample, 34 participants were tested in the 25% ignored repetition proportion condition, 30 in the 50% ignored repetition proportion condition, and 31 in the 75% ignored repetition proportion condition.

Materials. Materials were identical to those of Experiment 1, with the only exception of manipulating the proportion of ignored repetition trials instead of attended repetition trials. The 25% ignored repetition proportion condition was composed of 25% ignored repetition trials, 25% control trials, and 50% attended repetition control trials (that is, 75% trials without any stimulus repetition). Note that this condition was identical to the 0% attended repetition proportion condition of Experiment 1 in which we had found a reliable negative priming effect. The 50% and the 75% ignored repetition proportion conditions were modifications of the 25% ignored repetition proportion condition. The 50% ignored repetition proportion condition comprised 50% ignored repetition, 25% control, and 25% attended repetition control trials. The 75% ignored repetition proportion condition included 75% ignored repetition and 25% control trials. Note that the trial type conditions relevant for hypothesis testing—that is, 25% ignored repetition and 25% control trials—were identical in all three ignored repetition proportion groups. None of the proportion conditions included any attended repetition trials.

Procedure. The procedure was the same as in Experiment 1.

Design. The experiment comprised a 2×3 mixed design with trial type (ignored repetition vs. control) as within-subject variable and ignored repetition proportion (25% vs. 50% vs. 75%) as between-subjects variable. The primary dependent variable was participants' average reaction time, but error rates were also analysed.

The difference of the negative priming effect (ignored repetition – control) between the three levels of the ignored repetition proportion variable was relevant for our a priori power considerations. In order to detect a medium interaction effect, that is, of size $f = 0.25$, given a population correlation of $\rho = .5$ between the reaction time variables ignored repetition and control, and desired levels of $\alpha = \beta = .05$, data had to be collected from a sample of at least $N = 66$ participants (Faul et al., 2007). We were able to collect data from $N = 95$ participants so that the power was even larger (>.99). The level of alpha was maintained at .05 for all statistical decisions.

Results

Probe reaction times were evaluated only for trials in which prime and probe responses were correct.[4] The means of participants' average reaction times

[4] For control reasons, we ran a 2×3 MANOVA of the reaction time prime data with trial type (ignored repetition vs. control) as within-subject variable and ignored repetition proportion as between-subjects variable (25% vs. 50% vs. 75%). Prime response times did neither differ across groups nor between the trial type conditions, as there was neither a main effect of group, $F(2, 92) = 0.52$, $p = .60$, $\eta^2 = .01$, nor a main effect of trial type, $F(1, 92) = 0.14$, $p = .71$, $\eta^2 < .01$. However, the interaction between both variables was significant, $F(2, 92) = 3.61$, $p = .03$, $\eta^2 = .07$. This interaction effect seems to be a spurious error as none of the follow-up tests revealed a significant difference between ignored repetition and control trial primes. There were no effects in the 25% ignored repetition proportion group, $t(33) = -1.92$, $p = .06$, $d_z = 0.33$, the 50% group, $t(29) = 1.71$, $p = .10$, $d_z = 0.31$, or in the 75% group, $t(30) = 0.72$, $p = .48$, $d_z = 0.13$. For the prime error rates, there were no main effects of group, $F(2, 92) = 0.83$, $p = .44$, $\eta^2 = .02$, of trial type, $F(1, 92) = 0.13$, $p = .72$, $\eta^2 < .01$, or of an interaction between both variables, $F(2,92) = 2.52$, $p = .09$, $\eta^2 = .05$. On average, participants responded 1009 ms after prime stimulus onset and committed approximately 7.2% prime errors.

and error rates are presented in Figure 4. Figure 4 (upper panel) shows that the mean reactions in ignored repetition and control trials were crucially influenced by the ratio of ignored repetition trials.

A 2 × 3 MANOVA of the reaction time data with trial type (ignored repetition vs. control) as within-subject variable and ignored repetition proportion as between-subjects variable (25% vs. 50% vs. 75%) revealed neither a significant main effect of trial type, $F(1, 92) = 0.40$, $p = .53$, $\eta^2 < .01$, nor a main effect of ignored repetition proportion, $F(2, 92) = 1.15$, $p = .32$, $\eta^2 = .02$. The interaction between both variables, however, was

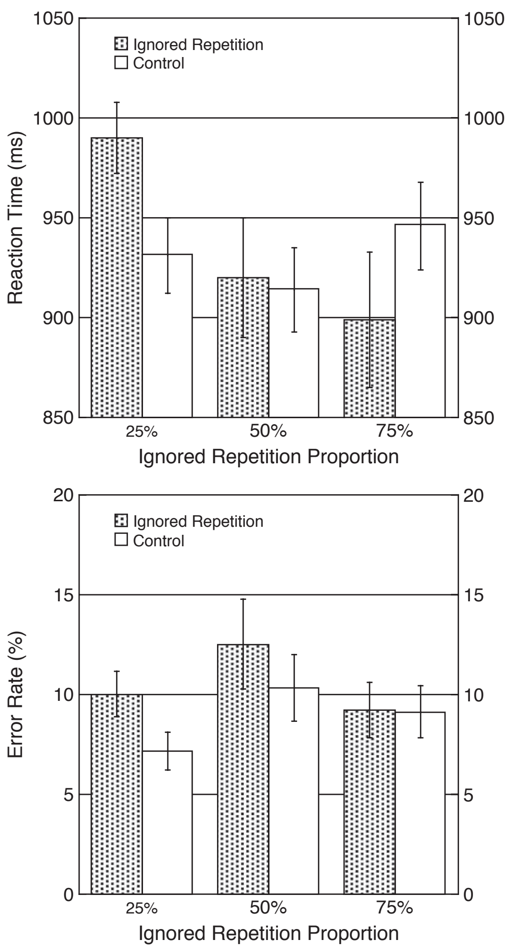

Figure 4. Mean reaction times (upper panel) and error rates (lower panel) as a function of trial type (ignored repetition vs. control) and ignored repetition proportion in Experiment 2. The error bars depict the standard errors of the means.

significant, $F(2, 92) = 10.38$, $p < .01$, $\eta^2 = .18$. Negative priming was significant in the 25% ignored repetition proportion condition, as is shown by follow-up tests using the Bonferroni-Holm method of protecting against α-error accumulation, $t(33) = 5.97$, $p < .01$, $d_z = 1.02$. In the 50% condition, there was no priming effect at all, $t(29) = 0.33$, $p = .74$ (two-sided testing), $d_z = 0.06$. In the 75% condition, ignored repetition trials were responded to somewhat faster than control trials, but using the Bonferroni-Holm method this effect must be classified as not significant, $t(30) = 2.11$, $p = .04$, $d_z = 0.38$.

An analogous analysis of the error data (lower panel of Figure 4) revealed a significant main effect of trial type, $F(1, 92) = 9.29$, $p < .01$, $\eta^2 = .09$, but neither a main effect of ignored repetition proportion, $F(2, 92) = 1.11$, $p = .33$, $\eta^2 = .02$, nor an interaction between these variables, $F(2, 92) = 2.22$, $p = .12$, $\eta^2 = .05$. Again, negative priming was significant in the 25% ignored repetition proportion condition, as is shown by follow-up tests, $t(33) = 3.94$, $p < .01$, $d_z = 0.68$. In the 50% condition, the negative priming effect just missed the preset criterion of statistical significance, $t(29) = 1.81$, $p = .08$ (two-sided testing), $d_z = 0.33$. In the 75% condition, there was no priming effect at all, $t(30) = 0.09$, $p = .93$ (two-sided testing), $d_z = 0.02$.

Discussion

Experiment 2 demonstrates that auditory negative priming can be subject to a modulation of trial proportions. When the proportion of ignored repetition trials was increased, the negative priming effect was significantly reduced (as in the 50% condition) or tended to be inversed (as in the 75% condition). Possibly, a large percentage of ignored repetition trials hits participants on the contingencies. As a consequence, they will learn to focus their attention to the prime distractor. This will facilitate processing of the same stimulus when it becomes the probe target in ignored repetition trials. In order to validate this possible explanation, we gave a postexperimental questionnaire to a subset of our participants (12 in the 25% condition, 13 in the 50% and in the 75% condition).[5] They were first asked whether they had noticed any systematics in the experimental trials. When they negated this question, testing was over. When they approved of the question, they were prompted to describe the systematics they had noticed. In the 75% and the 50% conditions, about half (six and seven, respectively) of the participants reported having noticed a certain regularity (but only a subset of these participants described a regularity that could be unambiguously identified as

[5] We abstained from questioning all of our participants because we were afraid of focusing their attention too much to the trial contingencies in upcoming related studies.

the correct one). In the 25% condition, there were only three participants who said so (but none of them unambiguously described the correct contingency). This result suggests that the larger percentage of ignored repetition trials leads to verbalisable knowledge of the contingencies. This knowledge, in turn, may lead to a strategic prime processing in that participants in the high proportion groups paid more attention to the prime distractor information knowing well that this would facilitate probe responding. This finding fits nicely with the results reported by Milliken and Rock (1997; see also Milliken et al., 1999) who could show that only those participants who were aware of the large number of repeated trials and accurately estimated its proportion did show a reversal to positive priming (Experiment 1) or no negative priming at all (Experiment 2).

An additional indication of a prime processing strategy with increased attentional allocation to the distractor would be a distribution of prime response times with longer prime responses pointing to increased prime distractor processing. Consistent with this idea, the overall prime reaction times in the 75% groups were the slowest of all three groups (1029 ms vs. 1000 ms in the 25% and 991 ms in the 50% group, respectively).

GENERAL DISCUSSION

We investigated whether auditory negative priming and its underlying mechanisms are susceptible to strategic factors known to influence the size of the visual negative priming effect. In Experiment 1, we manipulated the proportion of attended repetition trials in three steps (0% vs. 25% vs. 50%) and tested whether negative priming was modulated by this variation. At odds with results obtained in the visual modality, negative priming as measured in terms of reaction times was immune to this manipulation. There was also no modulation of prime response retrieval processes. Participants in all proportion groups exhibited a significant and approximately similar increase in prime–response retrieval errors in ignored repetition compared to control trials. In principle, the independence of negative priming from the attended repetition proportion manipulation would also be compatible with an inhibitory account (Houghton & Tipper, 1994; Tipper, 1985) that should not be sensitive to prime–probe target repetitions. However, given the fact that an exclusively inhibitory account is unable to explain the prime response retrieval effects found in all proportion groups of Experiment 1, inhibitory processes could, if anything, only complement episodic retrieval processes.

In sum, Experiment 1 allows to conclude that episodic retrieval processes in auditory negative priming take place automatically. They seem to be active even when prime retrieval is detrimental rather than beneficial for probe responding (as was the case in the 0% attended repetition proportion group). This finding deviates from what we know from the visual modality in which there is clear evidence for a strategic modulation of negative priming processes (Frings & Wentura, 2008; Kane et al., 1997; Lowe, 1979; but see also Simone et al., 2006).

Based on the automatic nature of episodic retrieval processes in the auditory modality, our second goal was to investigate how resistant auditory negative priming would be in the presence of a manipulation thought to influence strategic processing in a different way. To this end, we manipulated the proportion of ignored repetition trials, a manipulation known to reduce and even reverse the visual negative priming effect (Frings & Wentura, 2008, Exps. 2 and 3; Milliken et al., 1999; Milliken & Rock, 1997). In contrast to Experiment 1 but in accordance with findings from the visual modality, negative priming in Experiment 2 was reduced and even tended to be reversed when the proportion of ignored repetition trials was increased from 25% to 50% and 75%. Presumably, when participants notice that the prime distractor frequently reappears as probe target, they increase their attentional allocation to the prime distractor thereby facilitating subsequent probe responding. In a nutshell, our findings show that one of the processes underlying auditory negative priming, that is, episodic retrieval, takes place automatically whereas the phenomenon can be strategically modulated by acting upon attentional focussing during prime processing.

Our findings necessarily lead to the question why visual but not auditory negative priming seems to be susceptible to the manipulation of the proportion of attended repetition trials. There are several differences other than stimulus modality between the experiment by Frings and Wentura (2008, Exp. 1) and Experiment 1 reported here. Whereas Frings and Wentura manipulated proportions only during the training phase and the manipulation was rather moderate (50% vs. 33% attended repetition trials), we manipulated proportions throughout the experimental test phase with a stronger variation of proportions (0% vs. 25% vs. 50%). However, if anything, these procedural differences should have increased the effect of the proportion manipulation in our experiment. The same argument is true with respect to the larger number of trials (160 trials including training trials in Frings & Wentura, 2008, vs. 288 experimental trials in the present Experiment 1). We are not aware of any substantial argument why the procedural differences between the two studies should have provoked the differing results. Therefore, an explanation based on modality differences seems to be the most plausible one at the moment.

There is a long history of research identifying differences in short-term or immediate memory between the auditory and visual modality. For example, it is a well-documented fact that the recency effect in immediate memory tests is amplified for auditory in comparison to visual stimulus presentation (the so-called modality effect; for a review and discussion, see Nairne, 1988, 1990). It is outside the scope of this paper whether the modality differences can be accounted for by a longer duration of echoic traces (similar to the early idea of a precategorical acoustic storage model; see Crowder & Morton, 1969), a reduced probability of encoding visual modality-dependent attributes, or a tendency of relying on auditory rather than visual attributes as retrieval cues (Nairne, 1988, 1990). It seems plausible to assume that the memory trace of an auditory prime display is still very strong at the moment of the probe display—which can be compared to a cued recall test situation—thereby leading to successful retrieval of the prime episode with a large probability. In other words, due to the specific nature of auditory short-term memory, episodic retrieval processes may be fully functional by default, and therefore cannot be boosted any further.[6] In the case of visual prime and probe stimuli, however, the prime display trace is probably weaker and less salient and results in successful prime episode retrieval with a much lower probability. In this case, additional experimental context variables such as the proportion of attended repetition trials can induce a strategy of episodic retrieval, and thereby boost the amount of successfully retrieved prime episodes.

Note that the assumption of more pronounced prime retrieval processes in the auditory modality fits well with our observation that the prime response retrieval processes measured in previous experiments were clearly stronger in the auditory than in the visual modality (Exp. 1 vs. Exp. 2 in Hauke et al., 2009; Exp. 2 vs. Exp. 3 in Mayr & Buchner, 2006).

There is another line of research that argues for a strong automatic sensory/short-term memory functioning specific to the auditory modality that is unmatched in the visual modality. The so-called mismatch negativity (Näätänen, Gaillard, & Mantysalo, 1978; Näätänen, Paavilainen, Rinne, & Alho, 2007; Schröger, 2007) is an established ERP correlate that is thought to reflect the preattentive detection of a change (e.g., in frequency, intensity, or location of a sound) in repetitive auditory stimulation. The change detection response is thought to underlie a deviation from a neuronal trace that has been established during repeated stimulation with a standard stimulus, thus implying a strong memory model component in the auditory modality. What is more, this brain correlate of auditory memory is known to

[6] Note that our interpretation of an automatic retrieval process mediated by the high quality and robustness of auditory memory representations could also be conceptualised as a retrieval process that is subject to strategic control. In the latter case, our manipulation of attended repetition proportions would not have been strong enough to have any impact on retrieval due to the high quality of the auditory memory representations. However, applying another manipulation able to reduce the quality of the memory traces could possibly result in finding an attended repetition proportion effect. We thank Jason Leboe for making this point. It is an empirical question whether attended repetition proportion manipulations can have an effect on auditory negative priming under certain conditions (that degrade the quality of memory traces).

function automatically regardless of whether attention had been directed to the stimulus or not (for details, see Näätänen et al., 2007; Schröger, 1998). This ERP evidence of automatic auditory sensory/short-term memory functioning fits nicely with the evidence reported here, that is, with the finding of automatic retrieval in auditory negative priming.

Although modality effects in immediate memory and specific ERP correlates of auditory memory are only loosely related to the negative priming phenomenon, they point to a clear modality difference between visual and auditory memory in combination with a strong automatic component in auditory memory. These findings seem to be consistent with the present finding of a modality difference between auditory and visual negative priming in that the former but not the latter seems to be based on automatic retrieval processes.

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