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Auditory negative priming in younger and older adults

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Two experiments are reported in which performance of old and young adults in an auditory negative priming task was compared. Auditory negative priming was not smaller in old than in young adults. This result was independent of whether or not conditions were present that had previously been assumed to favour episodic retrieval, as opposed to inhibitory processes, as a basis of the negative priming phenomenon. The data from the present auditory negative priming experiments are incompatible with the global assumption that the efficiency of inhibitory attentional processes in general diminishes across the adult life span.

According to a popular theory of cognitive ageing, the efficiency of inhibitory attentional processes diminishes across the adult life span, allowing more irrelevant information to enter working memory, as a consequence of which performance on many cognitive tasks is reduced (Hasher & Zacks, 1988; Zacks & Hasher, 1994). The negative priming phenomenon has often been used in empirical tests of this theory. This phenomenon manifests itself in slowed-down or more error-prone reactions to recently ignored stimuli relative to control stimuli (for reviews, see Fox, 1995; May, Kane, & Hasher, 1995; Neill, Valdes, & Terry, 1995; Tipper, 2001). According to Tipper (1985; see also Dalrymple-Alford & Budayr, 1966; Houghton & Tipper, 1994; Neill, 1977) negative priming reflects the operation of an inhibitory attentional selection mechanism that prevents access of ignored objects to overt responses by suppressing competing distractor input. This mechanism enables more efficient responding to the current target, but causes a delay in responding when the previously ignored (and, hence, inhibited) distractor becomes the new target. Thus, an age-related reduction of the characteristic slow-down when reacting to a previously ignored object may be regarded as an indicator of reduced efficiency of the inhibitory attentional process.

Consistent with this view, there are quite a few studies in which negative priming was observed for younger but not for older adults (Connelly & Hasher, 1993; Hasher, Stoltzfus, Zacks, & Rypma, 1991; Kane, Hasher, Stoltzfus, Zacks, & Connelly, 1994; Kane, May,

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Hasher, Rahhal, & Stoltzfus, 1997; McDowd & Oseas-Kreger, 1991; Stoltzfus, Hasher, Zacks, Ulivi, & Goldstein, 1993; Tipper, 1991). However, there are also studies showing that negative priming is not selectively reduced in older adults (Gamboz, Russo, & Fox, 2000; Intons-Peterson, Rocchi, West, McLellan, & Hackney, 1998; Kieley & Hartley, 1997; Kramer, Humphrey, Larish, & Logan, 1994; Kramer & Strayer, 2001; Langley, Overmier, Knopman, & Prod' Homme, 1998; Little & Hartley, 2000; Schooler, Neumann, Caplan, & Roberts, 1997; Sullivan & Faust, 1993; Sullivan, Faust, & Balota, 1995).

Kane et al. (1997; see also May et al., 1995) have proposed a theoretical approach aimed at reconciling this pattern of data with the loss-of-inhibition theory of cognitive ageing. They assumed that the characteristic slow-down of responses to previously ignored stimuli may be caused by several mechanisms, and that the experimental context determines which mechanism is most likely to come into play. One of these mechanisms is the inhibitory attentional mechanism as specified by Tipper (1985; see also Houghton & Tipper, 1994), which should decrease in efficiency as a function of age according to the loss-of-inhibition theory of cognitive ageing. The other mechanism was assumed to be memory based and largely invariant across the adult life span. This so-called episodic retrieval mechanism has originally been proposed by Neill and colleagues (Neill & Valdes, 1992; Neill et al., 1995; Neill, Valdes, Terry, & Gorfein, 1992). The episodic retrieval account specifies that negative priming may be caused by the probe target's cueing the retrieval of the perceptually similar prime display, one part of which is the prime distractor. The prime 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 probe target, which is why responding to previously ignored targets takes more time than responding to control objects.

Consistent with this dual-mechanism approach, Kane et al. (1997) reported equivalent levels of negative priming for older and younger adults when the experimental context presumably facilitated the operation of the episodic retrieval mechanism. One such context, according to Kane et al. (1997), is characterized by the presence of trials on which the attended prime is repeated as the attended probe—that is, trials on which positive identity priming should be observed (henceforth attended repetition trials). The presence of such trials should serve to invoke the episodic retrieval mechanism within the task context because simply retrieving the prime information (including the response given to the previously attended prime) would lead to very large benefits when responding to the identical probe stimulus. Indeed, Kane at al. (1997, Exp. 3) reported significant negative priming in older adults when attended repetition trials were included. In contrast, in a previous study in which the same materials and procedure were used, but attended repetition trials were not included so that episodic retrieval was presumably not involved, only younger but not older adults showed negative priming. Also consistent with this view is that some previous demonstrations of negative priming in old adults included attended repetition trials (Sullivan & Faust, 1993; Sullivan et al., 1995).

However, Kieley and Hartley (1997), using a Stroop colour-word task, as well as Schooler et al. (1997), using a picture-word categorization task, showed negative priming in old adults despite the fact that no attended repetition trials were included in the experiments. Given this ambiguity of the empirical situation, one of the purposes of the present experiments was to contribute more evidence to help clarify this issue. We compared negative priming in younger and older adults in experimental contexts that included (Experiment 1) or did not include (Experiment 2) attended repetition trials.

Another purpose of the present research was to investigate whether the range of the currently available negative priming data and, hence, the potential reach of the theoretical accounts developed to explain possible developmental differences in negative priming, can be extended into the auditory domain. To date, virtually all negative priming studies used visual stimuli such as letters, words, colour bars, simple geometric shapes, line drawings of objects, or photographs of faces. Very little is known about negative priming when auditory stimuli are used (for some exceptions to the rule, see Banks, Roberts, & Ciranni, 1995; Buchner & Steffens, 2001), and all of the studies included in Verhaeghen and De Meersman's (1998) meta-analysis on age-related negative priming differences were restricted to the visual domain. However, it could be that developmental trends in the size of the negative priming effect differ between modalities. For instance, Banks et al. (1995) argued that attending to a tone while avoiding auditory distraction must operate almost entirely by internal processing mechanisms. Visual selection, in contrast, may be supported by peripheral mechanisms such as eye or head movements. Auditory selection by internal distractor inhibition may thus be regarded as much more demanding, leaving little or no room for compensating inhibitory deficits. As a consequence reductions in the efficiency of inhibitory mechanisms may become apparent more clearly in the auditory than in the visual domain, so that age differences in negative priming may be expected to be stronger and more reliable in the auditory than in the visual domain.

Finally, we wanted to compare the sizes of the negative priming effects in old and young adults using an experimental paradigm for which some evidence exists that inhibitory processes are indeed involved (for details, see Buchner & Steffens, 2001). In essence, participants heard pairs of tones displayed via headphones. One tone was presented to each ear. A click indicated the ear that had to be attended. Participants were asked to classify, by an appropriate keypress, the attended tone as originating from a "wind instrument" or a "string instrument". Each trial consisted of a prime pair and a probe pair of stimuli. Trials were separated by a pause. The primary contrast was between trials in which the ignored prime is repeated as the attended probe (henceforth ignored repetition trials) and between parallel trials with four different stimuli (the control trials).

The standard negative priming result should be that manual responding to the attended probe is slower on ignored repetition than on control trials. This is indeed what can be observed (Buchner & Steffens, 2001, Exp. 1). More interestingly for the current purposes is what happened when the manual response to the probe (but not to the prime) was replaced by a temporal order judgement (Buchner & Steffens, 2001, Exp. 2). Participants were simply to judge which of the two probe tones had occurred earlier. Two tones were in fact asynchronous only during the training phase, but were presented simultaneously during the experiment proper. It turned out that the act of ignoring a tone on a prime presentation resulted in a reduced probability of accepting that tone as antecedent on the subsequent probe presentation relative to the control condition in which the same tone had not occurred on the prime presentation.

This finding is consistent with the prediction of the distractor inhibition account according to which inhibitory processes suppress the competing distractor inputs, which, in turn, leads to less efficient signal processing when a previously ignored stimulus is presented again

(Houghton & Tipper, 1994; Tipper, 1985). Therefore, a tendency to perceive an ignored event as occurring later is to be expected. In contrast, such a result is not predicted by episodic retrieval, which is a response-based mechanism: The retrieval of the nonresponse information encoded with the ignored prime conflicts with the requirement to respond when the same stimulus is subsequently presented as the attended probe. It therefore cannot affect perceptual judgements such as those of the temporal order of auditory signals.

Note that these findings do not exclude the retrieval of nonresponse information from prior processing episodes (Neill & Valdes, 1992; Neill et al., 1995; Neill et al., 1992) as a factor for the classical, response-time variety of the negative priming phenomenon. The findings do imply, however, that episodic retrieval of nonresponse information *alone* cannot explain negative priming. In other words, these data are compatible with the assumption that inhibitory processes of the sort specified by Tipper (1985; see also Houghton & Tipper, 1994) also play a role in the experimental paradigm used by Buchner and Steffens (2001) in their Experiment 2 (with probabilities of temporal order judgements as dependent variables) and, hence, in their structurally equivalent Experiment 1 (with response times as dependent variables). Because the latter paradigm was also used in the present Experiment 1, the loss-of-inhibition theory of cognitive ageing predicts at least reduced negative priming for older adults. Experiment 2 went one step further by eliminating the attended repetition trials. If the dual-mechanism approach by Kane et al. (1997) is to be empirically tenable, then the lack of attended repetition trials should increase the relative contribution of inhibitory processes to the magnitude of the negative priming effect so that the reduction in negative priming of old relative to young adults should be even larger in Experiment 2 than in Experiment 1.

EXPERIMENT 1

Method

Participants

Participants were 52 young adults, 40 of whom were female, and 52 old adults, 40 of whom were female. Young adults were mostly students. They ranged in age from 19 to 31 years ($M = 23$). Old adults were recruited from local nursing homes. They ranged in age from 60 to 83 years ($M = 69$). All participants were tested individually and were paid for their participation.

None of the participants used hearing aids (this was a requirement for participating in the study). Older and younger participants did not differ with respect to their self-assessed health (relative to their age groups, and using categories of "very good", "good", "bad", and "very bad"[1]), $\chi^2(2) = 0.27$, $p > .88$, and hearing ability, $\chi^2(2) = 0.01$, $p > .97$, but older participants reported lower visual acuity, $\chi^2(2) = 8.72$, $p < .02$, and were happier with their lives, $\chi^2(2) = 6.16$, $p < .05$, than were the younger participants. Also, by a U test, older participants used more medication, $z = -5.91$, $p < .01$, and had lower digit spans, $z = -4.33$, $p < .01$.

[1]The questions were such that the same response categories were used for all self-assessments. The "very bad" category was never used by any of the participants in any of the self-assessments.

Materials

The stimuli were three digitized wind instrument (flute, trumpet, and saxophone) and three string instrument tones (grand piano, balalaika, and pizzicato violin). Each tone was 200 ms long, complete with attack and decay. The participants heard the tones over earphones that were fitted with high-isolation hearing protection covers and plugged directly into an Apple PowerBook computer.

A 20-ms metronome click indicated the ear (left or right) on which the to-be-attended tone would be presented. Participants reacted to the tones by pressing the "wind instrument" (arrow up) or "string instrument" (arrow down) key on the computer keyboard. These keys were aligned sagittally so as to avoid spatial compatibility effects between the tones' location and the required response.

Each of the 288 experimental trials consisted of a prime and a probe pair of stimuli. There were four basic types of trial: 72 ignored repetition trials (IR), 72 ignored repetition control trials (IRC), 72 attended repetition trials (AR), and 72 attended repetition control trials (ARC). Within each trial type, the attended primes and probes were presented to the same ear for one set of 36 unique trials (given the restrictions explicated below), whereas attended primes and probes were presented to different ears for the other set of 36 unique trials. This implies that on IR trials, the ignored prime changed location in the former case, but did not change location in the latter case. The sequence of trials within the experiment was random, and it was randomly determined for each trial whether the attended prime was presented to the left or to the right ear.

Each IR trial corresponded to one IRC trial in terms of the tone configuration except for the ignored primes, which differed but were taken from the same category (wind or string instrument). Each AR trial also corresponded to one ARC trial except for the attended primes, which differed but were taken from the same category. This is illustrated in Table 1. If negative, or positive, priming occurs with this arrangement of corresponding trials, then it must involve processes operating at the level of the stimulus identity of the tone and cannot be due to processes related to the response category.

Within each trial type, and between trial types, the absolute frequencies of the different tones were identical. The same was true for the frequencies of the combinations of attended and ignored tones, both within and between the prime and the probe pairs. On all trials, the attended and ignored stimuli were from different response categories.

The required response changed from prime to probe in IR and IRC trials and remained the same in AR and ARC trials so that the required reaction to the attended probe could not be predicted from the prime. However, this implies that IR trials can only be compared to IRC trials, and AR trials can only be compared to ARC trials.

Procedure

During training, participants heard and reacted to a single tone for 24 trials in which each of the six different tones was presented four times. On the next block of 48 training trials, the metronome click

TABLE 1
Examples of stimulus configurations (Experiment 1)

	Ignored repetition		*Ignored repetition control*		*Attended repetition*		*Attended repetition control*	
Stimulus pair	*Attended ear*	*Ignored ear*	*Attended ear*	*Ignored ear*	*Attended ear*	*Ignored ear*	*Attended ear*	*Ignored ear*
Prime	Flute	Piano	Flute	Balalaika	Flute	Piano	Trumpet	Piano
Probe	Piano	Trumpet	Piano	Trumpet	Flute	Balalaika	Flute	Balalaika

indicated the ear at which the to-be-attended tone would be presented (left or right, determined at random). After a 500-ms cue–target interval, a pair of tones was presented, one to the left and one to the right ear. Participants reacted to the attended tone by quickly pressing the "wind instrument" or the "string instrument" key.

Each of the 288 experimental trials began with the metronome click, followed by a 500-ms cue–target interval and the prime pair of tones. After the prime reaction, a 500-ms interval preceded the click that cued the to-be-attended probe. The temporal parameters were the same for the prime and probe tone pairs. Prime or probe reactions faster than 100 ms and slower than 4000 ms were counted as invalid, and the entire trial was repeated after a brief warning. (To anticipate, such errors were extremely infrequent, with rates less than .01, and the inclusion of repeated trials did not change any of the statistical conclusions.) After each trial, participants received feedback about the correctness of their prime and probe reactions. They initiated the next trial at their own discretion.

After every 10th trial, participants received a summary feedback about both their error percentage and average reaction time, but correctness was emphasized. After the final trial, all participants were informed about the purpose of the experiment.

Design

The design consisted of two 2 × 2 × 2 subdesigns. The ignored repetition subdesign comprised IR versus IRC trials as the levels of the within-subject priming factor and same versus different presentation sides of the attended prime and probe as the levels of the within-subject presentation side factor. The attended repetition subdesign differed by having AR versus ARC trials as the levels of the priming factor. Both subdesigns also comprised the two levels, young versus old adults, of the quasi-experimental age variable. The primary dependent variables were participants' reaction times, but error probabilities were also analysed.

Given a total sample size of $N = 104$ and $\alpha = .05$, effects of size $d_z = 0.35$ (cf. Cohen, 1977) could be detected with a probability of $(1 - \beta) = .95$ for the overall (positive or negative) priming effects.[2] Further, with $n_{old} = n_{young} = 52$ and $\alpha = .05$, effects of size $d = 0.80$ could be detected with a probability of $(1 - \beta) = .98$ for the age-related difference in the (positive or negative) priming effects. The level of α was set to .05 for all analyses reported in this article.

Results

Probe reaction times were evaluated only for trials in which both the probe and the prime reactions were correct. In other words, a trial was counted as an error when the prime reaction, the probe reaction, or both reactions were incorrect.[3] Pure guessing would therefore result in an error rate of .75, which is well above the observed error rates (although these were relatively high). The means of participants' average reaction times and the error rates are presented in the upper and lower panels of Figure 1, respectively.

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

[3] Note that the inclusion of prime errors in addition to the probe errors yields information about the proportion of correct trials underlying the reaction time data. The absolute error rate level is thus larger than what would result on the basis of the probe errors alone, but the important error rate differences between conditions are unaffected. This is so because prime errors will be distributed evenly across experimental and control trials, and including them is equivalent to adding a constant to the probe error rates.

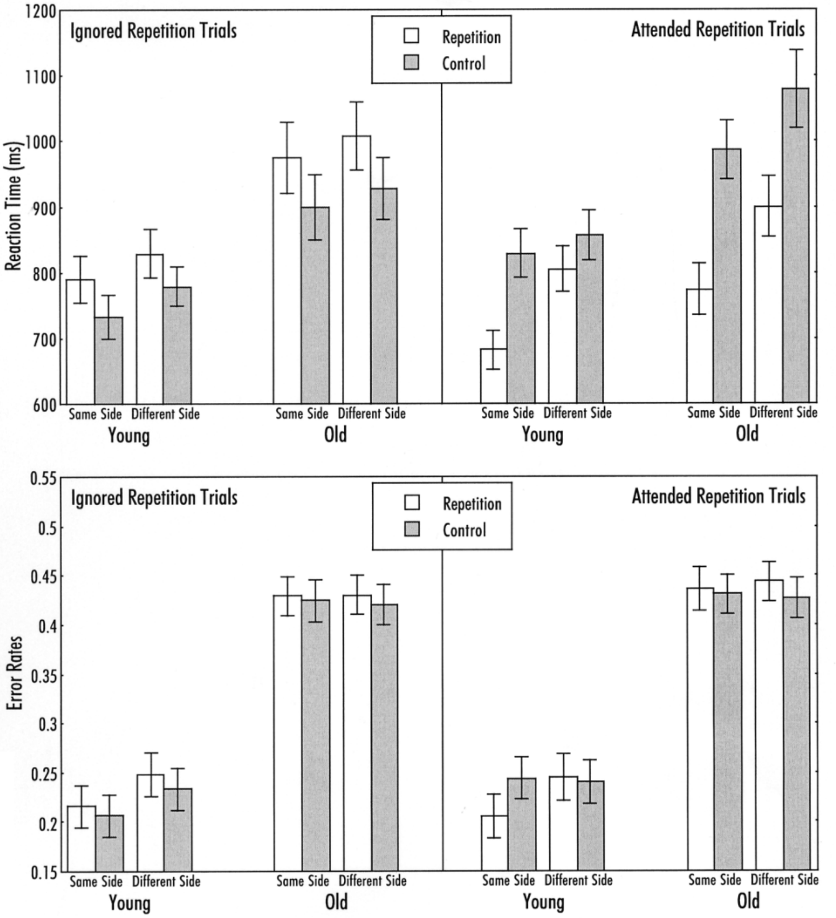

Figure 1. Reaction times (upper panel) and error rates (lower panel) as a function of trial type and presentation side for older and younger participants (Experiment 1). The error bars depict the standard errors of the means.

Old adults reacted more slowly than young adults. Reaction times on IR trials were longer than reaction times on IRC trials, and they were longer when the attended prime was presented to a different ear from that of the attended probe. Corresponding to these descriptive data, a 2 × 2 × 2 analysis of variance (ANOVA) with age group (young vs. old adults) as between-subjects variable and priming (IR vs. IRC) as well as presentation side (same vs. different) as within-subject variables showed significant main effects of age group, $F(1, 102) = 8.64$, $MSE = 347{,}309$, $p < .01$, of priming, $F(1, 102) = 39.98$, $MSE = 11{,}364$, $p < .01$, and of presentation side, $F(1, 102) = 7.94$, $MSE = 17{,}387$, $p < .01$. None of the interactions were significant, $F(1, 102) < 1.47$, $p > .23$. Follow-up t-tests showed that negative priming was significant for both young adults, $t(51) = 6.02$, $p < .01$, and for old adults, $t(51) = 4.16$, $p < .01$.

The error data ran parallel to the reaction time data in that young adults made fewer errors than old adults, $F(1, 102) = 49.43$, $MSE = 0.08$, $p < .01$, and participants made more errors on IR trials than on IRC trials, $F(1, 102) = 4.95$, $MSE = 0.002$, $p < .03$, and when the presentation side changed, $F(1, 102) = 6.98$, $MSE = 0.003$, $p < .01$. However, the main effect of presentation side must be qualified by a significant interaction between age group and presentation side, $F(1, 102) = 8.85$, $MSE = 0.003$, $p < .01$. The presentation side effect was significant only for young adults, $t(51) = 4.00$, $p < .01$, but not for old adults, $t < 1$. None of the other interactions were significant, $F(1, 102) < 0.39$, $p > .53$.

Reactions on AR trials were faster than reactions on ARC trials, and reactions again took longer when the attended primes and probes were presented to different ears. A 2 × 2 × 2 ANOVA with age group (young vs. old adults) as between-subjects variable and priming (AR vs. ARC) as well as presentation side (same vs. different) as within-subject variables showed significant main effects of age group, $F(1, 102) = 6.52$, $MSE = 319{,}904$, $p < .02$, of priming, $F(1, 102) = 112.40$, $MSE = 11{,}364$, $p < .01$, and of presentation side, $F(1, 102) = 59.18$, $MSE = 14{,}867$, $p < .01$. There was also an interaction between the age group and priming variables, $F(1, 102) = 12.22$, $MSE = 8896$, $p < .01$, indicating that positive priming was larger for old adults ($M = 196$ ms, $SD = 163$ ms) than for young adults ($M = 99$ ms, $SD = 116$ ms); for both groups the priming scores were significantly different from zero, $t(51)\text{s} > 6.14$, $p < .01$. The interaction between priming and presentation side was also significant, $F(1, 102) = 12.23$, $MSE = 8896$, $p < .01$, indicating that positive priming was larger when attended primes and probes were presented to the same ear ($M = 180$ ms, $SD = 170$ ms) than when they were presented to different ears ($M = 115$ ms, $SD = 183$ ms). No other interactions were significant, $F(1, 102) < 2.67$, $p > .10$.

With respect to the error data, there was a significant main effect of age group, $F(1, 102) = 47.90$, $MSE = 0.09$, $p < .01$, an interaction between the age group and priming variables, $F(1, 102) = 9.47$, $MSE = 0.002$, $p < .01$, and an interaction between the presentation side and priming variables, $F(1, 102) = 9.39$, $MSE = 0.002$, $p < .01$. The interactions reflected the fact that young adults made slightly fewer errors on AR ($M = 0.23$, $SD = 0.16$) than on ARC trials ($M = 0.24$, $SD = 0.17$), but old adults made slightly more errors on AR ($M = 0.44$, $SD = 0.15$) than on ARC trials ($M = 0.43$, $SD = 0.14$); also, slightly fewer errors were made on AR ($M = 0.32$, $SD = 0.19$) than on ARC trials ($M = 0.34$, $SD = 0.18$) when attended primes and probes were presented to the same ear, but slightly more errors were made on AR ($M = 0.34$, $SD = 0.18$) than on ARC trials ($M = 0.33$, $SD = 0.18$) when primes and probes were presented to different ears.

Discussion

Experiment 1 demonstrated a clear auditory negative priming effect for both young and old adults. In terms of raw reaction times, the negative priming effect was relatively large with a reaction time difference between IR and IRC trials of 53 ms and 79 ms for young and old adults, respectively. The positive priming effect was even larger with a reaction time difference between AR and ARC trials of 99 ms and 196 ms for young and old adults, respectively. The relative sizes of the negative and positive priming effects (roughly about 1:2) are in the order of magnitude of those reported by others for various different tasks (e.g., Buchner & Steffens, 2001; Fuentes, Humphreys, Agis, Carmona, & Catena, 1998; Neumann & DeSchepper, 1991; Schooler et al., 1997; Strayer & Grison, 1999; Tipper, 1985). The greater positive priming for older than for younger adults is also consistent with previous research

(Balota & Duchek, 1988; Bowles & Poon, 1985). Thus, the present results fit in with the pattern of data published elsewhere.

The negative priming results of Experiment 1 are unexpected from the viewpoint of the general loss-of-inhibition theory of cognitive ageing. The task used here has previously been shown to be likely to involve inhibitory processes (cf. Buchner & Steffens, 2001).[4] If there was an age-related decline in the efficiency of inhibitory processes, then older participants should have shown reduced negative priming, which was not the case. However, Kane et al. (1997) have proposed that, in some experimental contexts, the negative priming effect may be determined less, if at all, by inhibitory processes than by episodic retrieval. One such experimental context, according to Kane et al. (1997), is characterized by the presence of attended repetition trials because retrieving the prime information (including the response afforded by the prime) on these trials leads to very large benefits when responding to the identical probe stimulus. If one assumes that these benefits lead to a generalized prime retrieval strategy for all types of trials, then it is possible to argue that the experimental context of Experiment 1 (in which 25% of the trials were attended repetition trials) could have minimized the contribution of inhibitory processes for the benefit of (nonresponse) retrieval processes.

We think that given the results of Experiment 1, this explanation is not very satisfactory a priori, because significant contributions of episodic retrieval processes should have resulted in more negative priming on those IR trials on which the ignored prime and the attended probe were presented to the same ear rather than to different ears. On those IR trials, the probe was more similar to the prime. This should have facilitated the probe-triggered retrieval of the prime episode and, hence, should have increased the overall interference caused by the retrieval of the incompatible nonresponse tag associated with the prime distractor. However, the presentation side variable did not interact with the priming variable on ignored repetition trials, which is unexpected under the assumption that episodic retrieval contributed substantially to the negative priming effect.[5]

Nevertheless, we thought it important to perform this presumably more stringent test of the loss-of-inhibition theory of cognitive ageing along the lines suggested by Kane et al. (1997). This test required an experimental context without attended repetition trials so as to minimize further the potential contribution of episodic retrieval processes. This was implemented in Experiment 2. In addition, a few procedural details were adjusted in an attempt to increase the number of (error-free) valid trials available for computing the individual reaction time estimates. The training phase was extended, the presentation side manipulation was dropped (attended prime and probe tones were always presented to different ears), and the timing of events was slower.

[4] It has also been shown that neither feature mismatch (Park & Kanwisher, 1994) nor temporal discrimination (Milliken, Joordens, Merikle, & Seiffert, 1998) provide a satisfactory explanation of the negative priming results in this task (Buchner & Steffens, 2001).

[5] Note, however, that the two variables did interact on attended repetition trials, suggesting the prime-response retrieval does affect positive priming (see Buchner & Steffens, 2001, for parallel results).

EXPERIMENT 2

Method

Participants

Participants were 119 young adults, 68 of whom were female, and 125 old adults, 66 of whom were female. Young adults were mostly students. They ranged in age from 18 to 37 years ($M = 23$). Old adults were recruited from local nursing homes. They ranged in age from 59 to 81 years ($M = 67$). All participants were tested individually and were paid for their participation.

None of the participants used hearing aids (this was a requirement for participating in the study). Older and younger participants did not differ with respect to their self-assessed hearing ability (relative to their age groups, and using categories of "very good", "good", "bad", and "very bad"[6]), $\chi^2(2) = 0.91$, $p > .82$, but older participants reported lower overall health, $\chi^2(2) = 10.04$, $p < .01$, and were happier with their lives, $\chi^2(2) = 8.11$, $p < .01$, than were the younger participants. Older and younger participants also differed with respect to their self-assessed visual acuity, $\chi^2(2) = 15.28$, $p < .01$, but the pattern was such that older adults were over-represented in the "good" category and under-represented in the "bad" and "very good" categories. Finally, older participants were more likely to use medication, $z = -10.74$, $p < .01$, and had lower digit spans, $z = -2.90$, $p < .01$.

Materials

The materials were identical to those used in Experiment 1, with the following exceptions. Most important, there were two basic types of trial: ignored repetition trials (IR) and ignored repetition control trials (IRC). Attended repetition (AR) and attended repetition control (ARC) trials were omitted.

As mentioned in the Materials section of Experiment 1, the required response always changed from prime to probe in the IR and IRC trials, but remained the same in AR and ARC trials so that overall the probe reactions could not be predicted from the prime reactions. Thus, using the IR and IRC trial types from Experiment 1 alone would have been problematic. We therefore decided to use the complete set of 108 trials that can be constructed by combining all possible pairs of instruments for the prime stimuli with all possible pairs of instruments for the probe stimuli while taking into account two restrictions. First, on IR trials the ignored prime must be identical to the attended probe. Second, it must be possible to construct an IRC trial that is parallel to a particular IR trial, with the exception of the ignored prime, which must come from the same category as the tone at the same place in the corresponding IR trial. Of the complete set of 108 IR trials, a total of 36 trials were critical because they were structurally identical to the IR trials used in Experiment 1 in that the attended prime and the ignored probe on the one side and the ignored prime as well as the attended probe on the other were from different categories. The remaining 72 trials served as filler trials. In one subset of 36 filler trials the attended probe required the same response as the attended prime and, hence, the ignored prime was from the same category as that of the attended prime. In the other subset of 36 filler trials the prime and probe responses were different, but the trials differed in their stimulus composition from those of Experiment 1 in that the attended and ignored probes were from the same response category. In sum, within the complete set of 108 IR trials, the required probe response was the same as the required prime response on one third of the trials; the prime and probe responses differed on the remaining two thirds of the trials. We thought this sufficient to prevent participants from basing their probe responses on expectancies induced by the prime responses. However, it is important to note that if they did, then one should observe an overall reduction

[6]The questions were such that the same response categories were used for all self-assessments. As in Experiment 1, the "very bad" category was never used by any of the participants in any of the self-assessments.

of the negative priming effect relative to that observed in Experiment 1 (to anticipate, this was not the case).

For each of the 108 different IR trials, an IRC trial was constructed as in Experiment 1. More precisely, each IR trial corresponded to one IRC trial in terms of the tone configuration except for the ignored primes (see Table 1). However, only 36 of the IR trials and their parallel 36 IRC trials were structurally identical to the IR and IRC trials used in Experiment 1 in that (1) attended primes and probes were from different categories, and (2) attended and ignored tones were from different categories in both the prime and the probe stimulus pair. Only responses to these trials were evaluated. All other trials served as filler trials.

Procedure

The procedure was identical to that used in Experiment 1, with the following exceptions. In essence, there was more training, the timing of events was slower, and attended primes and probes were consistently presented to different ears. These measures were taken in an attempt to reduce the error rates, particularly for the elderly participants.

After the first 24 familiarization trials in which each of the six different tones was presented four times, participants were trained on 60 trials in which the metronome click indicated the ear at which the to-be-attended tone would be presented (left or right, determined at random). After a 1000-ms cue–target interval, a pair of tones was presented, one to the left and one to the right ear. Participants reacted to the attended tone by pressing, as quickly as possible, the "wind instrument" or the "string instrument" key, depending on the category to which the tone belonged.

The experiment consisted of 216 trials (36 IR trials and 36 IRC trials as well as 144 filler trials), each of which was composed of a prime and a probe pair of tones. A trial began with a brief "count-down", followed by the click. After a 1000-ms cue–target interval, the prime pair of tones was presented. Participants reacted by pressing the appropriate key. The interval between participants' reactions and the click preceding the probe pair of tones was 1000 ms. The cue click for the attended probe was always presented to the ear opposite to the ear to which the attended prime had been presented. The probe tone pair was then presented with the same temporal parameters as the prime tone pair.

Design

The experiment used a 2 × 2 design with IR versus IRC trials as the levels of the within-subject priming factor and young versus old adults as the levels of the quasi-experimental age variable. The primary dependent variables were participants' reaction times, but error probabilities were also analysed.

Given a total sample size of $N = 244$ and $\alpha = .05$, effects of size $d_z = 0.25$ (cf. Cohen, 1977) could be detected with a probability of $(1 - \beta) = .97$ for the overall negative priming effect. Further, with $n_{\text{old}} = 125$ and $n_{\text{young}} = 119$ and $\alpha = .05$, effects of size $d = 0.5$ could be detected with a probability of $(1 - \beta) = .97$ for the age-related difference in the negative priming effects.

Results

Probe reaction times were evaluated only for trials in which both the probe and the prime reactions were correct. The means of participants' average reaction times and the corresponding error rates are presented in the upper and lower panels of Figure 2, respectively.

Old adults reacted more slowly than young adults, and reaction times were longer on IR trials than on IRC trials. A 2 × 2 ANOVA with age group (young vs. old adults) as between-subjects variable and priming (IR vs. IRC) as within-subject variable showed significant main

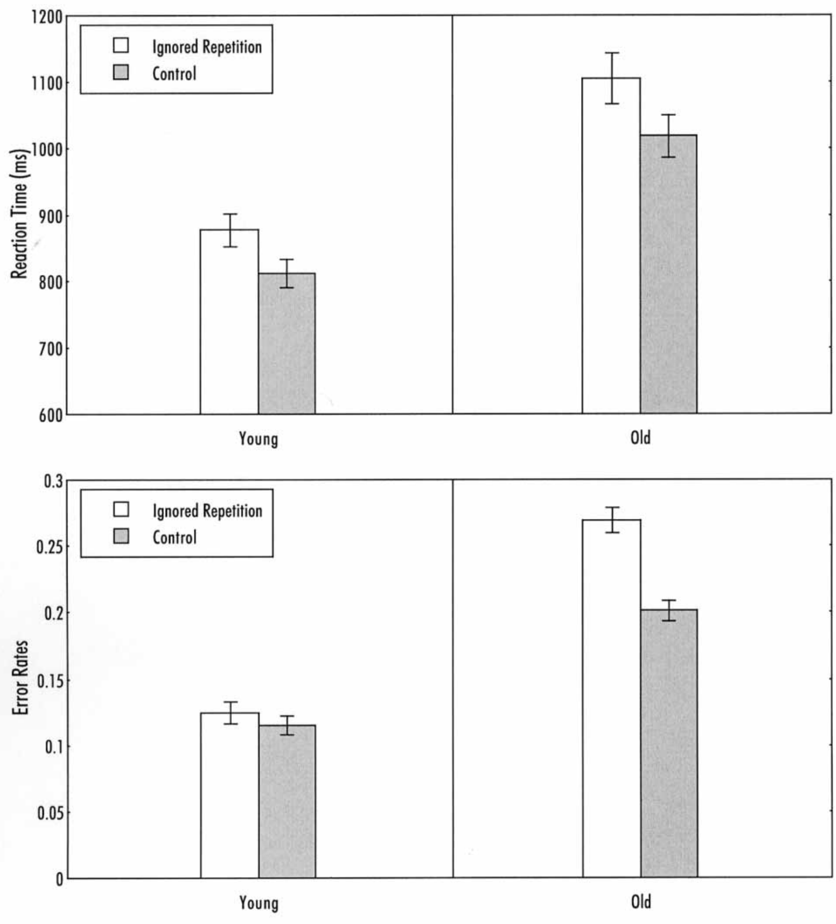

Figure 2. Reaction times (upper panel) and error rates (lower panel) as a function of trial type for older and younger participants (Experiment 2). The error bars depict the standard errors of the means.

effects of age group, $F(1, 242) = 28.97$, $MSE = 200{,}206$, $p < .01$, and of priming, $F(1, 242) = 38.59$, $MSE = 18{,}025$, $p < .01$. The interaction between both variables was not significant, $F(1, 242) < 0.75$, $p > .39$. Follow-up t-tests showed that negative priming was significant for both young adults, $t(118) = 5.75$, $p < .01$, and old adults, $t(124) = 4.07$, $p < .01$. A parallel analysis of the error data showed that young adults made fewer errors than old adults, $F(1, 242) = 125.94$, $MSE = 0.01$, $p < .01$, and that participants made more errors on IR trials than on IRC trials, $F(1, 242) = 48.88$, $MSE = 0.004$, $p < .03$. However, the main effect of the priming variable must be qualified by a significant interaction between age group and priming, $F(1, 242) = 28.57$, $MSE = 0.004$, $p < .01$. The priming effect was significant only for old adults, $t(124) = 7.87$, $p < .01$, but not for young adults, $t(118) = 1.35$, $p > .18$. The lack of a difference for young adults and, hence, a major factor contributing to the interaction between age group and priming may be largely due to a floor effect. The important point is, however, that the error data pattern does not compromise the analysis of the reaction time data.

Discussion

The results of Experiment 1 were replicated in that there was a clear auditory negative priming effect for both young and old adults. At a descriptive level, the negative priming effect in terms of the reaction time difference between IR and IRC trials was larger than it had been in Experiment 1 for both young and old adults, amounting to 65 ms and 86 ms, respectively. This increase seems closely related to the overall increase in reaction times for all participants (see Figures 1 and 2). The central result is that the negative priming effect was not reduced in older participants even with no attended repetition trials that should have stimulated episodic retrieval according to the dual-mechanism approach proposed by Kane et al. (1997). This finding is parallel to those reported by Kieley and Hartley (1997) and by Schooler et al. (1997) who used visual stimuli and also reported no age difference in negative priming in experimental situations without attended repetition trials.

GENERAL DISCUSSION

The data from the present auditory negative priming experiments are incompatible with the general assumption that the efficiency of inhibitory attentional processes diminishes across the adult life span (Hasher & Zacks, 1988; Zacks & Hasher, 1994) if one accepts the premise that the size of the negative priming effect is (also) a measure of those inhibitory processes. There are two reasons as to why one could accept this premise in the present context. First, the results did not differ as a function of whether (Experiment 1) or not (Experiment 2) the experimental context supposedly favoured the episodic retrieval mechanism (cf. Kane et al., 1997). Second, the results of Buchner and Steffens (2001) suggest that inhibition is indeed reflected in performance in the present task, even in the version realized in Experiment 1. In addition, the age-independence of the negative priming results in the auditory domain as evidenced by the present experiments is parallel to results obtained with visual stimuli using a Stroop colour-word task (Kieley & Hartley, 1997; Little & Hartley, 2000), a picture-word categorization task (Schooler et al., 1997), a letter-naming task (Gamboz et al., 2000; Langley et al., 1998), a word-naming task (Intons-Peterson et al., 1998), a letter identification task (Kramer et al., 1994; Langley et al., 1998), a picture identification task (Sullivan & Faust, 1993; Sullivan et al., 1995), a pointing task (Simone & McCormick, 1999), and a same–different picture comparison task (Kramer & Strayer, 2001), among others. Thus, across a wide variety of tasks and both within the visual and, in the present experiments, the auditory domain the evidence is mounting that the size of the negative priming effect does not differ between young and old adults.

How should these data be weighed against studies showing that only younger, but not older, adults show negative priming (Connelly & Hasher, 1993; Hasher et al., 1991; Kane et al., 1994; Kane et al., 1997; McDowd & Oseas-Kreger, 1991; Stoltzfus et al., 1993; Tipper, 1991)? Several substantive explanations have been offered, but neither the Kane et al.'s (1997) dual-mechanism approach (see the discussion sections of Experiments 1 and 2) nor target selection difficulty (cf. Gamboz et al., 2000) nor the difference between location and identity negative priming tasks (cf. Kramer et al., 1994) seem to be satisfactory explanations of the pattern of published results. In fact, Verhaeghen and De Meersman (1998) concluded from their meta-analysis that there was no evidence for the influence of moderator variables on the negative priming effect in young and old adults. A recent update of this meta-analysis confirms that conclusion (Gamboz, Russo, & Fox, 2002).

This raises the more fundamental question of whether substantive explanations are at all necessary to explain the published pattern of young–old differences in the negative priming effect. We think that the answer to this question could well be no. More precisely, there are at least two reasons for the apparent shortfall in negative priming for old as opposed to young adults in the published literature: a problem affecting standardized effect size measures and a selection-for-publication bias.

First, a higher frequency of statistically significant negative priming effects for young than for old adults is to be expected for a purely methodological reason, which is related to the size of the negative priming effect in terms of a standardized effect size measure. For repeated measures analyses with two levels (such as IR and IRC conditions) the effect size measure d_z (cf. Cohen, 1977) is defined as

$$d_z = \frac{|\mu_{x-y}|}{\sigma_{x-y}} = \frac{|\mu_{x-y}|}{\sqrt{\sigma_x^2 + \sigma_y^2 - 2\mathrm{cov}_{xy}}} = \frac{|\mu_{x-y}|}{\sqrt{\sigma_x^2 + \sigma_y^2 - 2\rho\sigma_x\sigma_y}} \qquad 1$$

Let variables x and y represent the reaction times in the IR and IRC conditions, respectively, so that d_z represents the effect size measure for the negative priming effect. Then μ_{x-y} is the difference between the IR and IRC reaction times (i.e., the negative priming effect in raw reaction times), σ_{x-y} is the standard deviation of this difference, σ_x and σ_y are the standard deviations of the reaction times in the IR and IRC conditions, and ρ is the correlation between the reaction times in the IR and IRC conditions. The effect size problem becomes obvious when sample estimates of these parameters are used to compute $\hat{d}_z$. As Hasher and Zacks (1988, p. 217) noted, "a major observation of age-related performance is the increase in variability among participants". In other words, $\hat{\sigma}_x$ and $\hat{\sigma}_y$ are expected to be larger for old than for young adults, as was the case for the present experiments (see Figures 1 and 2). Furthermore, at least in the present experiments, old adults also make more errors than young adults. Because fewer correct trials are available for computing individual IR and IRC reaction time estimates for old than for young adults, the reliability of the individual IR and IRC reaction time estimates will be lower for old than for young adults. As a consequence, $\hat{\rho}$ is expected be lower for old than for young adults. This was indeed the case for the present Experiment 1 ($\hat{\rho}_{\text{old adults}} = .84$ vs. $\hat{\rho}_{\text{young adults}} = .95$) and for Experiment 2 ($\hat{\rho}_{\text{old adults}} = .82$ vs. $\hat{\rho}_{\text{young adults}} = .88$). Both of these factors lead to the expectation that the denominator of Equation 1 may be considerably larger for old than for young adults. Thus, if we assume for simplicity that the raw reaction time difference between IR and IRC trials would be exactly identical for old and young adults, then it is obvious from Equation 1 that we would expect $\hat{d}_{z,\text{ old adults}} < \hat{d}_{z,\text{ young adults}}$. However, the assumption of equal reaction time differences between IR and IRC trials for old and young adults may not be adequate. In fact, recent meta-analyses (Gamboz et al., 2002; Verhaeghen & De Meersman, 1998) and our own data suggest that these differences are typically somewhat larger for old than for young adults. In terms of Equation 1 this would lead to a somewhat larger numerator for older than for younger adults, diluting the effects of larger variances and higher error rates on the effect size measures. Nevertheless, even though the raw reaction time difference between IR and IRC trials in the present experiments was always larger for old than for young adults ($\hat{\mu}_{x-y,\text{ old adults}}$ = 79 ms vs. $\hat{\mu}_{x-y,\text{ young adults}}$ =53 ms in Experiment 1 and $\hat{\mu}_{x-y,\text{ old adults}}$ = 86 ms vs. $\hat{\mu}_{x-y,\text{ young adults}}$ = 65 ms in Experiment 2), the size of the negative priming effect was always smaller for old than for young adults in both Experiment 1 ($\hat{d}_{z,\text{ old adults}}$ = 0.58 vs. $\hat{d}_{z,\text{ young adults}}$ = 0.83) and in Experiment 2 ($\hat{d}_{z,\text{ old adults}}$ = 0.36 vs. $\hat{d}_{z,\text{ young adults}}$ = 0.53). Thus, the finding of no statistically significant negative priming may be assumed to be more likely a priori for old than for young adults, particularly given the typically (way too) small sample sizes (see Gamboz et al., 2002, Table 1; Verhaeghen & De Meersman, 1998, Table 1).

Turning to the second problem, consider that the results of empirical research typically culminate in the binary decision derived from a statistical significance test: Researchers conclude that an effect is present (if $p < \alpha$) or not (otherwise). With respect to negative priming in young and old adults, four different patterns of conclusions are possible (although not equally likely): (1) Both young and old adults show a negative priming effect; (2) young, but not old adults show the effect; (3) old, but not young adults show the effect; (4) neither young nor old adults show the effect. Without doubt, and independent of the true state of affairs, all four data patterns occur in real empirical research. However, the publication probability of pattern (3) is certainly smaller than that of pattern (1) or pattern (2). The finding of no negative priming in young adults will appear "anomalous" to most researchers. As such, pattern (3) data are likely to fall victim to the common belief that anomalous findings arise if something went wrong with the experiment, and clearly journal space for (seemingly) flawed experiments would be difficult to find. Thus, the set of published findings is probably biased towards more frequent reports of negative priming effects for young than for old adults.

To summarize, both the selection-for-publication bias and the effect size problem lead to an expected pattern of published data that favours more frequent and, on average, larger negative priming effects for young than for old adults. This must be taken into account when considering the pattern of published results and, of course, when appraising results of meta-analyses such as those reported by Verhaeghen and De Meersman (1998) and by Gamboz et al. (2002) in which, at a descriptive level, the average size of the negative priming effect was still larger for younger than for older adults.

A somewhat unsatisfactory situation may arise as a partial result of the effect size problem not only in meta-analyses, but in individual studies as well. More precisely, the standard statistical evaluation of the untransformed reaction time data may favour the null hypothesis of no age difference in negative priming—that is, an additive model according to which IR and IRC reaction times differ by the same constant for young and old adults. At the same time, the IR–IRC difference may be descriptively larger for old than for young adults. This has stimulated several researchers also to report their results in terms of a proportional reaction time increase on IR trials relative to the IRC baseline (Gamboz et al., 2000; Kramer & Strayer, 2001), showing that the proportional increase was very similar for old and young adults. We think that such an analysis is informative, but decided to follow the related approach preferred by Little and Hartley (2000) as well as by Verhaeghen and De Meersman (1998) which amounts to analysing whether the group reaction times (RT) for both young and old adults can be fit by a simple linear model according to which

$$RT_{IR} = b_0 + b_1 \cdot RT_{IRC} \qquad 2$$

The scope of this analysis is, of course, limited in the present study as there were only six data points to fit (reaction times from the two presentation side conditions of Experiment 1 and one condition of Experiment 2 in each of two age groups). The results are presented in Figure 3.

A first notable aspect of these data is the relatively good fit of the simple linear model to the data of both age groups ($R^2 = .99842$). Even without a statistical test it seems relatively clear that there is not much room for improvement by allowing for different slopes and intercepts of the functions for young and old adults. Second, the intercept estimate for the present auditory task situation (–40 ms) is very close to that reported by Verhaeghen and De Meersman (1998, –36 ms) and also close to that reported by Gamboz et al. (2002, –20 ms) for both age groups for a large set of experiments using visual stimuli, although all of these estimates are somewhat lower than the sample intercept reported by Little and Hartley (2000, –90 ms). More important, perhaps, the estimate of the slope parameter in our auditory task (1.13) is also roughly in the order of magnitude of those reported by Verhaeghen and De Meersman for young (1.10) and old adults (1.08) as well as of that reported by Gamboz et al. (1.06) and by Little and Hartley (1.14) for visual tasks. To be sure, such an analysis has little, if any, explanatory power, but it helps to constrain models designed to explain the effects of ageing on the processes that bring about the negative priming phenomenon, and it points to a parallelism in negative priming in the visual and the auditory domain.

In conclusion, the present data add to the growing body of research showing that negative priming does not diminish with age, and they extend the empirical basis for this conclusion

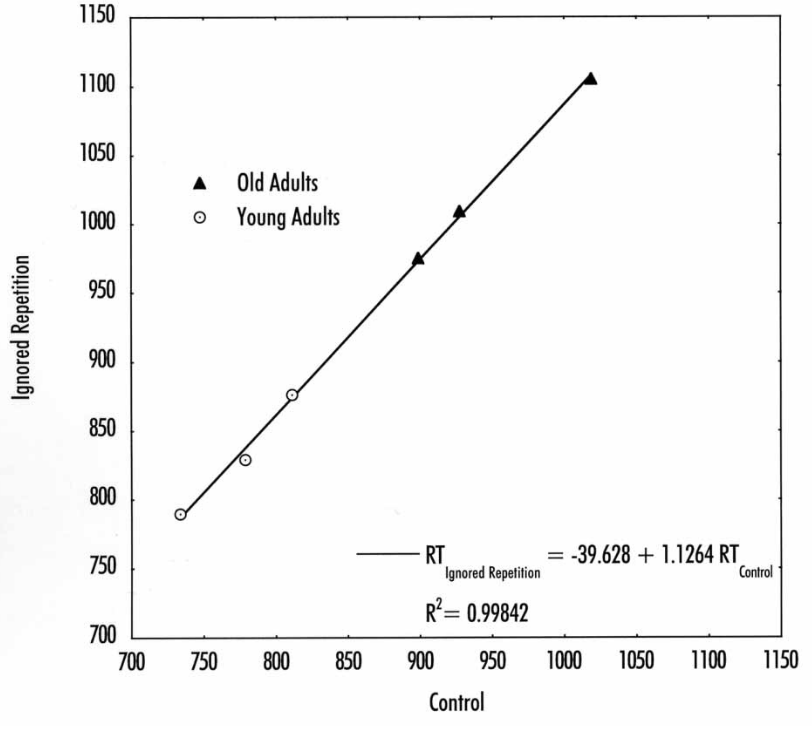

Figure 3. Mean reaction times in the ignored repetition conditions as a function of the mean reaction times in the control conditions, along with the best fitting linear regression function and regression line.

into the auditory modality. The conclusion holds independently of whether (Experiment 1) or not (Experiment 2) conditions were present that supposedly favour an episodic retrieval mechanism according to Kane et al. (1997; see also May et al., 1995). This result, too, fits well with the conclusions reached by others (Kieley & Hartley, 1997; Schooler et al., 1997) for the visual domain. Finally, it may be worth noting that despite the equivalence in their self-assessments, the older participants in the present experiments may be suspected to be less well functioning cognitively than the younger participants because the former were recruited from nursing homes. If anything, then, the sample of older participants was biased such that one would have expected reduced negative priming for the elderly, which was not observed.

In this sense, the data from the present auditory negative priming experiments are incompatible with the general assumption that the efficiency of inhibitory attentional processes diminishes at a global level across the adult life span (Hasher & Zacks, 1988; Zacks & Hasher, 1994). The data are not inconsistent with the assumption that specific inhibitory functions may show selective age-related declines (cf. Kramer et al., 1994), but this is beyond the scope of this article.

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