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Equivalent irrelevant-sound effects for old and young adults

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Three experiments are reported in which a total of 182 old and 193 young adults recalled sequences of digits presented visually in silence or accompanied by office noise. In each experiment, an effect of irrelevant sound was found—that is, a reduction of serial recall due to auditory distraction. Old adults exhibited poorer serial recall than did young adults, but the irrelevant-sound effect was equivalent in both age groups. This was true even though the sound level of the irrelevant sound was adjusted to each individual's hearing capability, and the effect remained whether or not the difficulty of the serial recall task was equated across age groups. These results are problematic for the inhibitory deficit theory of cognitive aging, which predicts that old adults should be more susceptible to auditory distraction than are young adults.

Reduction in cognitive functioning associated with old age is extremely well documented. So-called *common-cause theories* of cognitive aging assume that a basic deficit or changes in a small number of primitives can explain most age-related declines in cognitive functioning. Several higher order factors have been proposed to explain the apparently uniform age-related decline in cognitive processing efficiency across a wide range of tasks—for example, reduced inhibitory control over the contents of working memory (Hasher & Zacks, 1988), reduced working memory capacity (Salthouse, 1990), or slowing of processing speed (Salthouse, 1996).

The *inhibitory deficit theory*, originally proposed by Hasher and Zacks (1988), claims that a central deficit in attention plays a critical role in the understanding of the age-related decrease in cognitive functioning. According to this view, old adults suffer from a deficient inhibitory control system that (1) fails to prevent task-irrelevant information—either environmental events or internal thoughts—from gaining access to working memory; (2) fails to delete information from working memory that was once active but is no longer relevant or was activated inadvertently; and (3) fails to restrain prepotent but inadequate information from seizing control of working memory. These three functions of inhibition are referred to as the *access*, *deletion*, and *restraint* functions of inhibitory control. As a consequence of the impairment in these functions in old age, working memory of old adults is occupied by irrelevant information, and ultimately the functional capacity of working memory is reduced and the use of relevant information is disrupted (Hasher, Tonev, Lustig, & Zacks, 2001; Hasher, Zacks, & May, 1999; Zacks, Hasher, & Li, 2000).

An important implication of this theory for the research reported here is that, given the assumed age-related deficit in the access function of inhibitory control, old adults should be distracted much more easily by environmental events than are young adults (Hasher et al., 2001; Hasher et al., 1999; Lustig & Hasher, 2001; Lustig, Hasher, & Tonev, 2001). Specifically, old adults' "ability to ignore a wide range of stimulation, from background music, to television noise, to a ringing telephone" (Zacks & Hasher, 1994, p. 241) is thought to be severely impaired. Consistent with these assumptions, old adults have been shown to be more disrupted than younger adults by the presence of distractor words when reading (Duchek, Balota, & Thessing, 1998; Dywan & Murphy, 1996; Langley, Overmier, Knopman, & Prod'Homme, 1998; Salthouse, Atkinson, & Berish, 2003), especially when the distractors are meaningfully related to the target text (Carlson, Hasher, Connelly, & Zacks, 1995; Connelly, Hasher, & Zacks, 1991; Li, Hasher, Jonas, Rahhal, & May, 1998). Age differences have also been found in the ability to understand spoken language in the presence of noise (Pichora-Fuller, Schneider, & Daneman, 1995; Schneider, Daneman, & Pichora-Fuller, 2002; Tun, O'Kane, & Wingfield, 2002; Tun & Wingfield, 1999), and this result has sometimes been interpreted as evidence for an age-related decline in auditory selective attention (Hasher et al., 2001; Tun et al., 2002). Barr and Giambra (1990) found that old adults had more difficulties shadowing words presented to the left ear when distractor words were presented to the other ear in a dichotic listening task. Chao and Knight (1997) asked participants to indicate whether two subsequent sounds were identical. Old adults were more impaired than young adults by the presence of distractor sounds during the interval between the comparison sounds. These data, along with additional electrophysiological evidence, have led to the conclusion

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that old adults suffer from loss of prefrontal suppression over the primary acoustic regions, resulting in increased interference in short-term memory.

The supposition of an impairment in the access function of inhibitory control leads to the prediction that old adults should have more difficulties coping with auditory distraction while performing a task that relies on working memory performance. One means of examining the disruption of a working memory task by acoustic distractors is the irrelevant-sound paradigm. In this paradigm, sequences of visually presented verbal items are shown either in silence or accompanied by acoustic distractors. The *irrelevant-sound effect* refers to the reduction in serial recall performance when irrelevant sound is played either during presentation of the visual materials or during a brief retention interval. The level of impairment in serial recall seems to be mainly determined by the degree of "changing states" (roughly defined as abrupt changes in pitch and amplitude) inherent in the irrelevant auditory material (Jones & Macken, 1993, 1995; Jones, Macken, & Murray, 1993; Jones, Madden, & Miles, 1992). In contrast, the effect is not sensitive to the sound level of the auditory distractors (as long as the level is between 40 and 76 dB(A)—i.e., the sound pressure level of the auditory distractors is above the auditory threshold but below the pain threshold; see Colle, 1980; Ellermeier & Hellbrück, 1998). Likewise, neither the meaningfulness of the distractors (Buchner, Irmen, & Erdfelder, 1996; Jones & Macken, 1993, 1995; Salamé & Baddeley, 1982; Tremblay, Nicholls, Alford, & Jones, 2000) nor the semantic similarity between the distractors and the memorized items (Buchner et al., 1996) affects serial recall performance.

Recently, converging evidence has led to the suggestion that the irrelevant-sound effect might, at least in part, reflect attentional distraction; for instance, negatively valent distractors impair serial recall more than do neutral words (Buchner, Mehl, Rothermund, & Wentura, 2006; Buchner, Rothermund, Wentura, & Mehl, 2004). These findings are consistent with the feature model (Neath, 1999, 2000) and the *attention-and-memory* framework (Cowan, 1995), the latter of which has been used as a basis for the model of working memory within the inhibitory deficit theory (Hasher et al., 1999). Furthermore, Baddeley and Larsen (2003) argued in favor of attention's involvement in the irrelevant-sound paradigm. They suggested that a top-down attentional mechanism serves to modulate the reactivity of specialized neural populations in response to task instructions by actively inhibiting the processing of acoustic distractors. These suggestions were motivated by data from a PET study (Gisselgård, Petersson, Baddeley, & Ingvar, 2003) in which decreased activity was observed in structures related to initial phonological processing and verbal working memory during a serial recall task relative to during a control task.

An attentional interpretation of the irrelevant-sound effect is also supported by a developmental study using the irrelevant-sound paradigm. Elliott (2002) found that the irrelevant-sound effect was more pronounced in children than in adults, and she attributed this result to a deficit for young children in inhibitory mechanisms that could attenuate the influence of the distractor sound. Given that such group differences in the irrelevant-sound effect do indeed reflect group differences in inhibitory control, and provided that old adults do indeed show an inhibitory deficit in attentional control, as suggested by Hasher and Zacks (1988), a similar group difference in susceptibility to auditory distractors should emerge when comparing the irrelevant-sound effect for old and young adults.

Last but not least, the fact that the irrelevant-sound paradigm is appropriate for testing the inhibitory deficit theory is also obvious from the examples that have been used in the past to illustrate this theory. For instance, Lustig, Hasher, and Tonev (2001) stressed that the increased distractibility of old adults has

> important implications for the ability of old adults to maintain their optimal performance at home and in the workplace. Noisy or visually cluttered environments may be fine for young adults—think of a teenager doing homework in his or her bedroom with the stereo blasting—but older adults may be disrupted by such distraction. (p. 118)

An additional advantage of using the irrelevant-sound paradigm to test the inhibitory deficit theory is that the empirical fact that needs to be explained—worse working memory performance by old as opposed to young adults—is already present in the task. If old adults are worse at immediate serial recall than are young adults, this is an empirical phenomenon that the inhibitory deficit theory could explain in terms of the reduced inhibitory functioning that supposedly characterizes old adults. It would then follow that old adults' reduced working memory function should also be more susceptible to interference from distractors than is the working memory of young adults. In other words, if serial recall is worse in old than in young adults, then according to the inhibitory deficit theory, the irrelevant-sound effect must necessarily be larger for old than for young adults.

We are aware of three studies that have used the irrelevant-sound paradigm to test the inhibitory deficit theory (i.e., Beaman, 2005; Belleville, Rouleau, Van der Linden, & Collette, 2003; Rouleau & Belleville, 1996). Contrary to their initial expectations, neither Rouleau and Belleville nor Belleville et al. found age differences in susceptibility to irrelevant sound. Beaman replicated these results by showing that task-irrelevant speech and nonspeech sounds were no more distracting for old adults than for young adults. These results should thus lead to the conclusion that the inhibition of unwanted auditory information is not impaired in old age. However, there are several reasons why these studies need to be replicated and extended before such a conclusion should be drawn.

First, the studies of Rouleau and Belleville (1996) and Belleville et al. (2003) suffered from low statistical power. In both cases, samples of only 16 old and 16 young adults were tested. Therefore, the probability of detecting even large age differences in the size of the irrelevant-sound effect, according to the effect size conventions of Cohen (1988), was only .59 in both studies. With a medium effect size, the power dropped to less than .28. Hence, it is possible that the absence of a significant age × irrelevant sound interaction was just a consequence of this lack of power. A second problem of Rouleau and Belleville's and Belleville et al.'s studies is that possible sensory deficiencies in the old adults were insufficiently addressed. More precisely, in the latter study, the problem was completely ignored, and the former study relied only on self-reported "normal" hearing levels for both groups of adults. However, it is well established that old age can be associated with severely impaired hearing capabilities (see, e.g., Fozard & Gordon-Salant, 2001). Because of the destruction of hair cells in the inner ear and of neurons in the acoustic nerve, as well as a loss of mobility of the ossicles in the tympanum, the quality of the acoustic signal that is sent up to higher cortical centers can be dramatically impaired, and much less of an unattended sound signal may be processed by old than by young adults. With respect to the irrelevant-sound effect, the absolute sound level seems to be irrelevant for young adults with typically good hearing capabilities, as long as the signal is clearly audible (Colle, 1980; Ellermeier & Hellbrück, 1998). However, this might not be true for old adults in whom an age-correlated loss of hearing capability has caused a change in the quality of the perceived acoustic signal. Such adults could perceive fewer, or less pronounced, changing-state elements in the irrelevant auditory signal. Changing states are known to be the major determinant of the impairment in working memory performance due to irrelevant sound (Jones & Macken, 1993, 1995; Jones et al., 1993; Jones et al., 1992). Thus, if the reduced quality of the perceived acoustic signal resulted in fewer abrupt changes in amplitude and frequency reaching the central processing areas, this would benefit old adults selectively and help compensate for any increased distractibility by the irrelevant sound. In this way, age-related declines in hearing ability could mask age-related deficits in inhibiting distractor sounds.

Beaman's (2005) series of experiments represented an improvement over the Rouleau and Belleville (1996) and Belleville et al. (2003) studies, but a few issues still remain. First, although Beaman used larger samples than did either Rouleau and Belleville or Belleville et al., it seems desirable to use samples even larger than Beaman's in order to increase confidence, in case we need to conclude in favor of the null hypothesis of no difference in the irrelevant-sound effect between young and old adults. Second, Beaman addressed the problem of age-related differences in hearing by correlating the irrelevant-sound effect with audiometric scores. This correlation was positive, but small and not statistically significant. However, it may be problematic to conclude from this finding that age-related differences in hearing abilities did not affect the size of the irrelevant-sound effect. For instance, one or both of the measures that were used may not have been sufficiently reliable, in which case they would not correlate with each other simply because of their psychometric properties. Even if both measures were highly reliable, however, another problem would remain. It is well known that cognitive abilities are positively correlated with sensory functioning, presumably because both sets of measures are sensitive to changes in the underlying physiological architecture of the brain (Lindenberger & Baltes, 1994; Lindenberger, Scherer, & Baltes, 2001). Thus, a decrease in the efficiency of cognitive inhibition in older participants might well be accompanied by a decrease in hearing ability, and the latter quality could mask the effects of an inhibitory deficit, such that distraction by irrelevant sound could stay constant although hearing ability (and the efficiency of inhibitory processes) was reduced. Hence, the finding of a nonsignificant correlation between hearing ability and the size of impairment caused by irrelevant sound cannot rule out the possibility that a negative interrelation exists but is masked by a positive interrelation between inhibitory deficits and sensory decline. Third, unlike Rouleau and Belleville and Belleville et al., Beaman did not adjust for age differences in serial recall. The possibility of floor and ceiling effects in old and young adults, respectively, thus weakens the validity of his data. In addition, there is a certain danger that without adjustment for memory span, the task could be inherently different for old and young adults, because previous evidence has suggested that when a task is very difficult, people may change their strategy for holding visually presented verbal items in working memory, moving from the default strategy for this situation to one that is less prone to interference from auditory distractors (Baddeley, 2000; Beaman & Jones, 1997, 1998). If this were true for a subgroup of old adults with low digit spans, these participants might show no irrelevant-sound effect at all, simply because they relied on a mnemonic strategy that was less prone to interference from auditory distractors. This situation could have led to an underestimation of the irrelevant-sound effect in old adults.

Our Experiment 1A was designed as a replication of Rouleau and Belleville (1996), Belleville et al. (2003), and Beaman (2005), with two major changes. First, hearing ability was systematically assessed and was used to determine the sound level at which the auditory distractors were presented, so that the sensory quality of the distractor sound was equivalent across age groups. Second, the sample size was increased relative to the previous studies, so that even a medium-sized effect could be detected with sufficient statistical power.

In addition, the following changes were made to the experimental procedure. First, the irrelevant sound was presented both during encoding of the to-be-remembered items and during a short retention interval. In Beaman's (2005) experiments, irrelevant sound was only presented during the retention interval. Although it has been shown that the irrelevant-sound effect is of the same size whether the sound is presented at the same time as the visual material or during retention (Buchner et al., 2004; Jones & Macken, 1993; Miles, Jones, & Madden, 1991), the possibility remains that an additional effect of irrelevant sound specific to old adults could occur at encoding, when the additional task of phonologically recoding the visually presented verbal items must be accomplished. The finding that old and young adults are equally disrupted by the irrelevant sound in the present experiments would refute the existence of such an additional age-specific irrelevant-sound effect at encoding. Second, Beaman speculated that his use of only a small set of one-syllable nonwords and pure tones as the to-be-ignored sounds, along with fixed timing and a standardized presentation rate, may also have minimized the likelihood of detecting age differences in distractibility. This problem was also eliminated in the present experiments by using complex sounds that differed from trial to trial as the distracting materials. If these differences in materials and procedure are nonessential, we would expect a direct replication of the results of Rouleau and Belleville (1996), Belleville et al. (2003), and Beaman (2005)—that is, an irrelevant-sound effect of the same size for young and old adults.

EXPERIMENT 1A

Method

Participants. We recruited 95 community-dwelling old adults, 64 of whom were female, and 105 young adults, 77 of whom were female. The old adults were mobile and self-dependent (they lived in their own households and did not rely on external care). Thus, the sample consisted of relatively vital old adults, as is common in experiments testing the inhibitory deficit theory (e.g., Connelly et al., 1991; May, Hasher, & Kane, 1999). These participants were recruited through contacts with so-called neighborhood networks (run by churches and charity organizations) that provide social meetings, computer courses, and foreign language courses for old adults. The old adults ranged in age from 60 to 86 years ($M = 66.8$, $SD = 6.4$). Most young adults were recruited from the university (except for 3 who were recruited through personal contacts). They ranged in age from 18 to 30 years ($M = 22.3$, $SD = 2.7$). All participants were tested individually in a quiet room and were paid €5 for participation.

All participants reported normal or corrected-to-normal vision. None of the participants used hearing aids (this was a requirement for participating in the study). The old and young adults did not differ with respect to their self-assessed hearing ability [relative to their age groups, and using the categories "very good," "good," "bad," and "very bad"; $\chi^2(2) = 2.99$, $p > .39$] or in their overall contentment with life [$\chi^2(2) = 1.36$, $p > .72$], but they did differ with respect to their self-assessed health [$\chi^2(2) = 15.99$, $p < .01$; the old adults were underrepresented in the "very good" category and overrepresented in the "bad" category] and their self-assessed visual acuity [$\chi^2(2) = 11.81$, $p < .01$; the old adults were underrepresented in the "very good" category]. In addition, the old adults were less well educated than the young adults (13 of the old adults had 9 years of schooling, 48 had 10 years, and 34 had 13 years, whereas only 1 young adult had 9 years of schooling, 2 had 10 years, and 102 had 13 years); note, however, that massive changes have taken place in the German educational system over the past six decades, and it is thus very difficult to interpret years of education as an indicator of general cognitive functioning. Finally, according to a U test, the old participants were more likely to use medication ($z = -6.11$, $p < .01$) and had poorer visual acuity ($z = -7.69$, $p < .01$) when tested with a self-designed visual acuity test that consisted of a white sheet of paper with 10 rows of 10 digits printed in black upright Arial font, with font size descending from 24-pt to 4-pt. In this test, participants' task was to read the digits at a viewing distance of 1 m. The ordinal number of the line with the smallest font size in which all digits could still be identified correctly served as our ad hoc measure of visual acuity. Visual acuity was assessed while participants were wearing their normal corrective lenses.

Materials. To determine individual hearing thresholds, a file was created that consisted of 10 bursts of pink noise that lasted for 300 msec, with 500 msec of silence interspersed between the bursts. The noise bursts differed in sound level and were sorted in order of descending amplitude. When played at full sound level, using the same computer and headphones that would be used in the experiment, the sound levels of the noise bursts corresponded to 50, 45, 40, 38, 36, 34, 32, 30, 28, and 26 dB(A).

All of the to-be-remembered lists consisted of nine target items. They comprised sequences of digits sampled randomly with replacement from the set $\{1, 2, \ldots, 9\}$. A total of 32 such lists were generated for each participant, with 16 lists in each irrelevant-sound condition (irrelevant sound present vs. absent). Two lists, one for each condition, served as practice lists. The items were presented at the center of a 14-in. TFT monitor. The numbers were written in black upright Arial font on a white background. Viewing distance was approximately 50 cm, although head position was not constrained. At this distance, each target digit subtended about 2º horizontally and 2.9º vertically.

The sound files used in the irrelevant-sound trials consisted of digitized office noise with high variability in rhythm, amplitude, and frequency. Different kinds of sounds were identifiable, including both speech and nonspeech sounds. The speech sounds were composed of comprehensible short sentences like "Good morning!" or "Can I help you?" in a language that was familiar to the participants (German). The speech sounds were spoken by female and male voices. The nonspeech sounds consisted of a combination of noises produced by footsteps, typing, printers, fax machines, telephones, and other office gear. Altogether, there were 30 different sound files, each 20 sec in length. The participants heard the office noise over headphones that were fitted with high-isolation hearing protection covers and plugged directly into an Apple iBook computer. When played at full sound level, the mean sound level of the auditory distractors corresponded to about 79 dB(A).

Procedure. The participants were tested individually in a single session. Prior to the start of the experiment, individual hearing thresholds were determined in order to adjust the sound levels of the distractor stimuli to the hearing capabilities of the participants. To this end, the parameter estimation by sequential testing (PEST) procedure was used (Macmillan & Creelman, 1991), an adaptive method of determining thresholds. The sound level was iteratively adjusted so that the participants could detect 5 of the 10 bursts of pink noise. More precisely, participants first heard a sequence of sound bursts played at 44, 39, 34, 32, 30, 28, 26, 24, 22, and 20 dB(A) and reported how many of the bursts they heard. If they heard more than 5, the sound level was adjusted downward as prescribed by the PEST rules; if they heard fewer than 5, the sound level was adjusted upward as prescribed by the PEST rules. The auditory distractors played in the irrelevant-sound condition in the experiment proper were played at a mean sound level that was about 43 dB(A) louder than the hearing threshold determined by the procedure just described (i.e., than the fifth loudest sound burst in the final sequence of the threshold test). Thus, the upper limit on the sound level of the auditory distractors was 79 dB(A). This upper limit was used in order to prevent hearing damage and to preclude arousal effects from compromising the interpretability of the data.

Following the determination of the individual hearing thresholds, the participants received their instructions for the experiment proper. They were assured that all sounds they would hear were irrelevant and should be ignored. They were advised not to speak the to-be-remembered items out loud during the presentation phase or the retention interval, but they were allowed to use covert rehearsal. Two practice trials were administered, one from each condition, and the data from these trials were excluded from the analysis. The test phase consisted of 30 trials with 15 repetitions of each of the two sound conditions. The order of the trials during the test phase was randomly determined.

Each of the 2 practice trials and 30 test trials began with the presentation of a visual warning signal centered in the computer screen and three successive beeps that warned the participants that a sequence was about to be presented. Following the offset of the visual warning signal, the screen went blank for 1,200 msec. Then, the sequence of nine to-be-recalled digits was presented. Each digit was presented for 800 msec, followed by a 400-msec blank interstimulus interval. The retention interval after each list was 4 sec long. After the retention interval, nine question marks appeared on the screen, corresponding to the nine serial positions. This was the signal for the participant to commence recall of the list items in the order of presentation. The digits were entered via the number keys of the computer keyboard. Typing the first digit replaced the first question mark with that digit, typing the second digit replaced the second question mark, and so on. The participants were told to press a button labeled “don’t know” (the zero key on the number keypad) for each digit they could not recall. They were also allowed to correct their responses by using the arrow keys to move the current selection to another position, at which any prior entry could be replaced. After replacing all of the question marks by numbers or “don’t know” responses, the participants were asked to initiate the next trial by pressing the space bar. If the space bar was pressed before all question marks were replaced, a visual warning was shown that lasted 1,500 msec. No time pressure was imposed.

In the irrelevant-sound trials, the participants heard office noise during the list presentation and during the retention interval, but not during the recall phase. The irrelevant sound was delivered binaurally via headphones. The office noise was faded in, beginning 1,200 msec before and reaching full sound level at the onset of the first digit. The noise continued until the presentation of the question marks. For each irrelevant-sound trial, a different sound file was used. The sound files were selected randomly.

After a block of five trials, the participants received summary feedback about the number of items correctly recalled and were encouraged to rest briefly. On average, the experiment lasted about 45 min, after which the participants were informed about the purpose of the experiment.

Design. A 2 × 2 × 9 factorial design was used. Age group (old vs. young) was the quasi-experimental between-subjects variable. The within-subjects variables were irrelevant sound (present vs. absent) and serial position. The dependent variable was participants’ serial recall performance—that is, the number of digits correctly recalled at the serial position at which they had been presented.

Given a total sample size of 200 ($N_{\text{old}} = 95$, $N_{\text{young}} = 105$) with $\alpha = .05$, an effect of size $f = 0.25$ (a medium effect in terms of the conventions suggested by Cohen, 1988) could be detected for the age × irrelevant sound interaction with a probability of $1 - \beta = .94$.[1] The level of α was set at .05 for all analyses reported in this article.

Results

For the old adults, the distractor sound was presented at a level that ranged from 54 to 79 dB(A), *Mdn* = 70. Only 3 of the old participants reached the maximum sound level. The statistical conclusions reported below were not altered when these individuals were excluded from the analysis. For the young adults, the distractor sound level ranged from 48 to 74 dB(A), *Mdn* = 63. The sound was played significantly louder for the old adults than for the young adults, as revealed by a *U* test ($z = -8.64$, $p < .01$).

Figure 1 illustrates the serial recall performance across serial positions in both irrelevant-sound conditions for both age groups in terms of the proportion of items recalled correctly. A 2 × 2 × 9 repeated measures MANOVA with age (old vs. young) as the between-subjects variable and irrelevant sound (present vs. absent) and serial position as within-subjects variables revealed significant main effects of age group [$F(1,198) = 134.73$, $p < .01$, $\eta^2 = .41$], irrelevant sound [$F(1,198) = 43.91$, $p < .01$, $\eta^2 = .18$], and serial position [$F(8,191) = 302.77$, $p < .01$, $\eta^2 = .93$]. Follow-up *t* tests using the Bonferroni–Holm method of protecting against α error accumulation (Holm, 1979) showed that the irrelevant-sound effect was significant for both old adults [$t(94) = 4.61$, $p < .01$, $\eta^2 = .18$] and young adults [$t(104) = 4.79$, $p < .01$, $\eta^2 = .18$]. The most relevant interaction, between age group and irrelevant sound, was not significant [$F(1,198) = 0.03$, $p = .86$, $\eta^2 < .01$].

The interaction between age and serial position reached significance [$F(8,191) = 16.44$, $p < .01$, $\eta^2 = .41$]. This interaction reflects that the decrease in serial recall performance from Serial Positions 1 to 7 was more pronounced in the old than in the young adults. The significant interaction between irrelevant sound and serial position [$F(8,191) = 2.46$, $p < .05$, $\eta^2 = .09$] is due to the fact that the irrelevant-sound effect was less pronounced at later serial positions. The three-way interaction between age, irrelevant sound, and serial position was not significant [$F(8,191) = 1.27$, $p = .26$, $\eta^2 = .05$]. To see whether the absence of the age × irrelevant sound interaction was due to a younger subgroup of the old adults who preserved resistance to interference, we performed an additional analysis in which only those old adults were included who were above the median age for their group. This analysis resulted in the same statistical conclusions as the first analysis (except that in this case, the irrelevant sound × serial position interaction failed to reach statistical significance).[2]

Discussion

Given that the irrelevant-sound effect is known to be a robust phenomenon and that ample demonstrations exist of serial recall performance declining with age (e.g., Maylor, Vousden, & Brown, 1999), the main effects of irrelevant sound and age were expected, and they show that the present experiment can be regarded as a typical irrelevant-sound experiment with typical age-related performance differences. The old adults showed poorer serial recall performance than did the young adults. In other words, the old adults showed a working memory decrement that the inhibitory deficit theory would attribute to reduced inhibitory functioning. However, the impairment in serial recall due to auditory distractors was equally large in both age groups. Thus, the decrease in working memory capacity among old in comparison with young adults was unrelated to working memory interference caused by the irrelevant sound. The present results are consistent with those reported by Rouleau and Belleville (1996), Belleville et al. (2003), and Beaman (2005). An important point is that no age × irrelevant sound interaction was observed, despite the facts that the present experiment had considerably more statistical power than previous studies have had and that the amplitude of the irrelevant sound was individually adjusted to the hearing capabilities of the participants. Also, the irrelevant sound was played during both encoding and retention of the to-be-remembered items, rendering it unlikely that there was an additional effect of irrel-

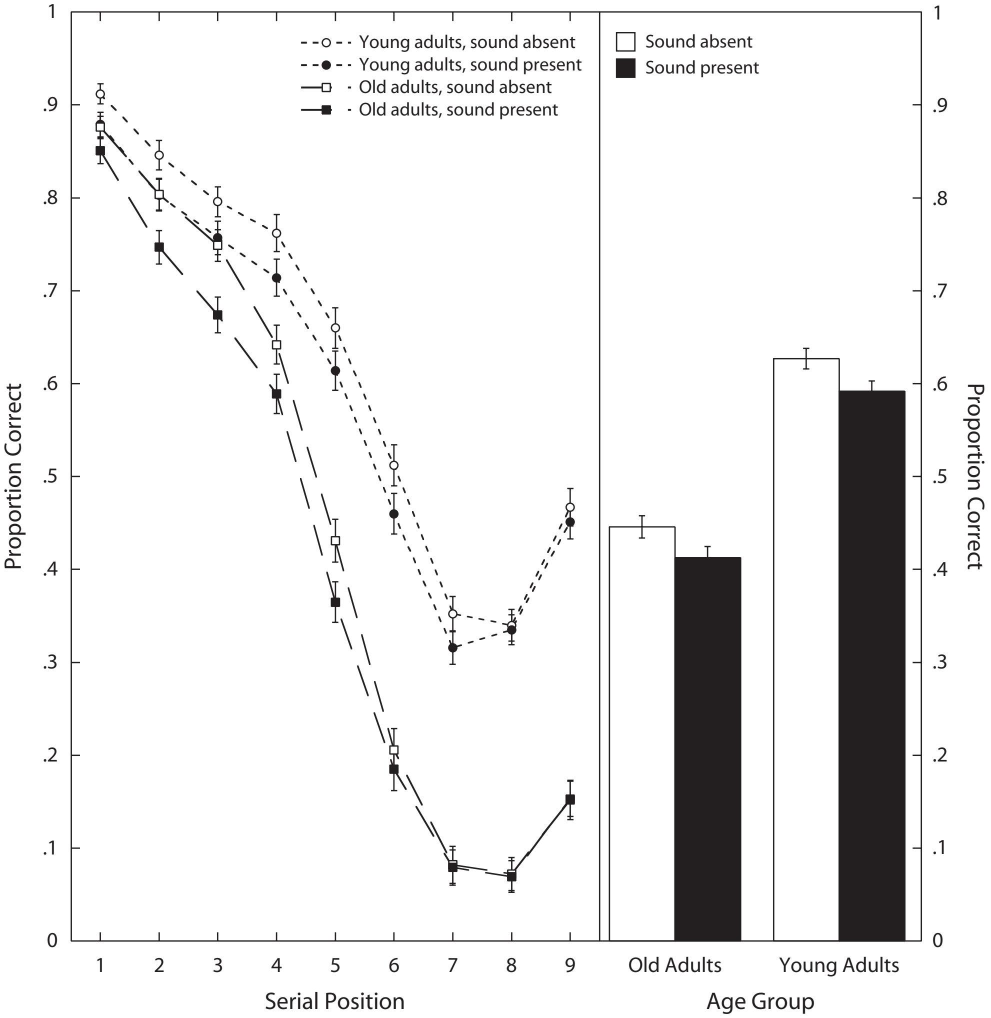

Figure 1. (Left) Proportions of items recalled correctly at each serial position in Experiment 1A, as a function of irrelevant-sound condition and age group. (Right) The overall serial recall performance of each group in each condition. The error bars represent standard errors of the means.

evant sound at encoding that is specific to old adults (cf. Beaman, 2005).

EXPERIMENT 1B

We thought it important to replicate the results of Experiment 1A using a modified procedure. In order to exclude the possibility that the old adults had more difficulty than the young adults using the keyboard to type in their responses, the participants were now asked to vocalize the recalled digits.

Method

Participants. The participants were 42 old adults, 29 of whom were female, and 42 young adults, 22 of whom were female. Old adults ranged in age from 60 to 80 years (*M* = 68.2, *SD* = 5.3). Young adults ranged in age from 18 to 25 years (*M* = 23.3, *SD* = 1.7). All participants reported normal or corrected-to-normal vision. None of the participants used hearing aids, which was a requirement for participating in the study. The data pertaining to the participants' years of formal education as well as their self-assessed visual acuity, hearing ability, general health, and contentment with life were lost as a result of an experimenter error. However, both the young and the old adults were drawn from the same populations as the participants in Experiment 1A, so the sample of Experiment 1B was very likely to have had similar characteristics.

Materials. The materials were identical to those used in Experiment 1A.

Procedure. The procedure was identical to that of Experiment 1A, with the following exceptions. Instead of typing, participants vocalized the digits they could recall as soon as the question marks appeared. "Don't know" was the required response for digits that could not be recalled. The digits were immediately typed into the computer keyboard by the experimenter, who was highly trained in typewriting. In that way, it was possible to assure that the participants had the same visual feedback for their responses as in the previous experiments. The typed digits were later validated using a tape-recording of the entire experimental session.

Design. The design was identical to that of Experiment 1A. Given a total sample size of 84 ($N_{\text{old}} = 42$, $N_{\text{young}} = 42$) at $\alpha = .05$, an effect of size $f = 0.4$ (a large effect in terms of the conventions suggested by Cohen, 1988) could be detected for the age × irrelevant sound interaction with a probability of $1 - \beta = .95$.

Results

For the old adults, the distractor sound was presented at a level that ranged from 66 to 79 dB(A), *Mdn* = 74. For the young adults, the distractor sound level ranged from 62 to 73 dB(A), *Mdn* = 64. The sound was played significantly louder for the old adults than for the young adults, as revealed by a *U* test ($z = -8.64, p < .01$). Note, however, that in this experiment, sound level was only allowed to vary between a minimum sound level of 62 and a maximum sound level of 79 dB(A). A total of 9 old adults and 13 young adults reached these limits. The statistical conclusions reported below were not altered when these individuals were excluded from the analysis.

Figure 2 illustrates the serial recall performance across serial positions in both irrelevant-sound conditions for both age groups in terms of the proportion of items recalled correctly. These results were very similar to those of Experiment 1A, although the overall level of performance was lower, presumably because vocalizing the remembered items interfered somewhat with the serial recall task. Nevertheless, we obtained significant main effects of age group [$F(1,82) = 53.17, p < .01, \eta^2 = .39$], irrelevant sound [$F(1,82) = 20.44, p < .01, \eta^2 = .20$], and serial position [$F(8,75) = 235.87, p < .01, \eta^2 = .96$]. Follow-up *t* tests using the Bonferroni–Holm method of protecting against α error accumulation (Holm, 1979) showed that the irrelevant-sound effect was significant for both old adults [$t(41) = 2.43, p = .01, \eta^2 = .13$] and young adults [$t(41) = 3.83, p < .01, \eta^2 = .26$]. Just as in Experiment 1A, the interaction between age group and irrelevant sound was not significant [$F(1,82) = 2.59, p = .11, \eta^2 = .03$]. If anything, the trend in this experiment was toward *less* pronounced susceptibility to auditory distraction in the old adults. The interaction between age group and serial position reached significance [$F(8,75) = 5.63, p < .01, \eta^2 = .38$], but the interaction between irrelevant sound and serial position [$F(8,75) = 0.69, p = .70, \eta^2 = .07$] and the three-way interaction between age group, irrelevant sound, and serial position [$F(8,75) = 0.75, p = .65, \eta^2 = .07$] did not. An additional analysis

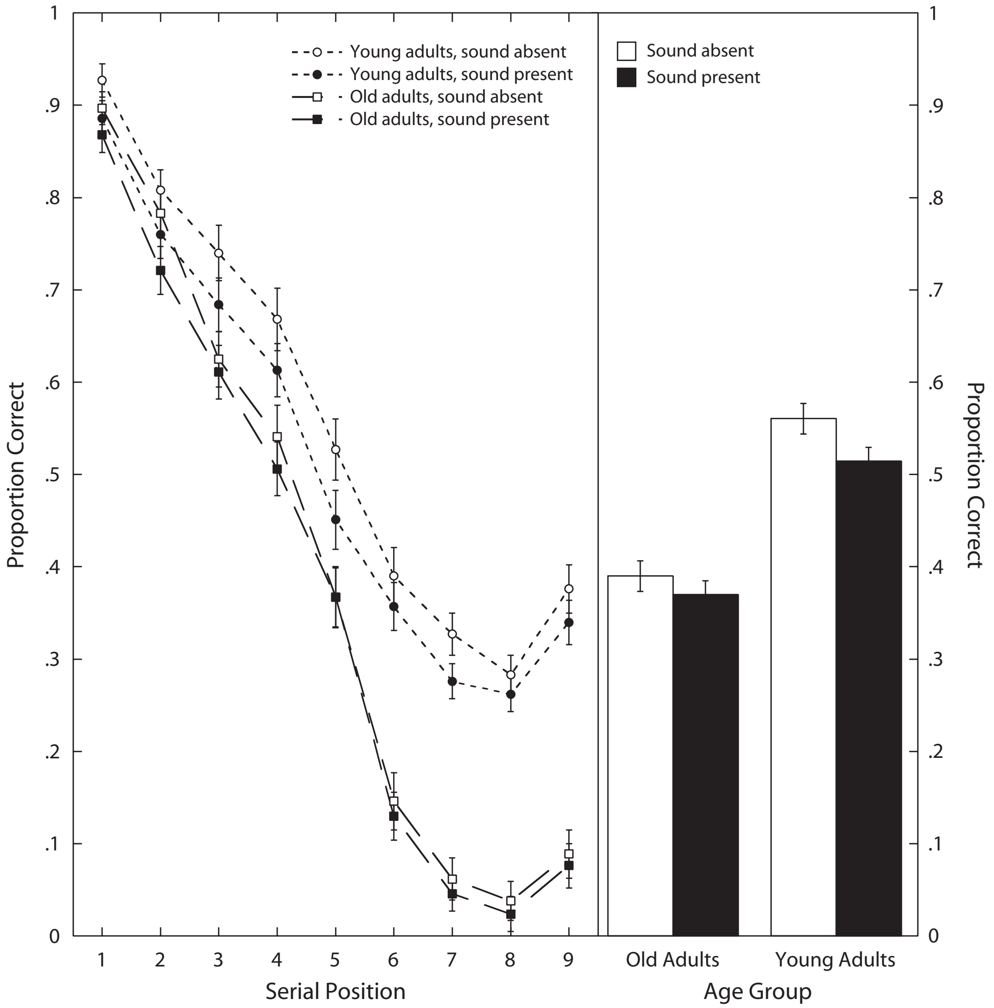

Figure 2. (Left) Proportions of items correctly recalled at each serial position in Experiment 1B, as a function of irrelevant-sound condition and age group. (Right) The overall serial recall performance of each group in each condition. The error bars represent standard errors of the means.

in which only those old adults above the median age for their group were included resulted in the same statistical conclusions as the first analysis.[3]

Discussion

In sum, main effects of about the same size as those found in Experiment 1A were replicated in Experiment 1B. What is more, in both experiments the size of the irrelevant-sound effect was smaller for old than for young adults. The results of Experiments 1A and 1B thus consistently show that old and young adults were equally affected by irrelevant sound, even when the distractor sound level was individually adjusted to the participants' hearing capabilities.

Experiments 1A and 1B were modeled after the typical irrelevant-sound experiment (Salamé & Baddeley, 1982, 1989), which is why we presented nine to-be-remembered visual digits, a number that very likely exceeded participants' digit spans. The reasoning behind this is that participants holding a large number of items in working memory should have no spare resources left to cope with an irrelevant sound, so the risk of ceiling effects should be relatively low. However, in the present context this paradigm may have been problematic, because floor effects could have masked an age difference in susceptibility to auditory distraction. For instance, note that old adults' performance in Experiments 1A and 1B was much lower than that of young adults, particularly at the later serial positions. At the same time, the difference between irrelevant-sound conditions was decreased at these later positions. Thus, it is possible that the old adults did not show a more pronounced decrement in performance in the noise-present condition simply because their serial recall performance was minimal even without distracting noise, so that no further reduction in performance was possible. This could have masked an age difference in distractibility.

Furthermore, there is a certain danger that without adjustments for memory span, the task could have been inherently different for the old than for the young adults. Previous evidence suggests that the size of the irrelevant-sound effect decreases when the serial recall task is very difficult (i.e., when the to-be-remembered sequences are very long). The reason for this trend might be a change in the dominant mnemonic strategy when the number of the to-be-remembered items exceeds a participant's working memory capacity (Baddeley, 2000; Beaman & Jones, 1997, 1998). This could be seen as problematic if one regards the "default" strategy for short lists of verbal items as a prerequisite for irrelevant-sound interference, because it could have led to the paradoxical situation that those individuals with low working memory capacity may have been less prone to irrelevant-sound interference. Ultimately, this would complicate the interpretation of the results of Experiments 1A and 1B. Therefore, we decided to replicate Experiment 1A, but this time we equated task difficulty for the two groups by adjusting the difficulty of the serial recall task according to participant digit span levels.

EXPERIMENT 2

Method

Participants. The participants were drawn from the same populations as those in Experiments 1A and 1B. As in the previous experiments, most of the old adults were recruited through contacts with neighborhood networks, but 5 were recruited through advertising in local newspapers. The participants were 45 old adults, 38 of them female, and 46 young adults, 30 of them female. The old adults ranged in age from 60 to 80 years ($M = 67.8$, $SD = 5.6$), and the young adults ranged in age from 17 to 30 years ($M = 23.9$, $SD = 3.4$).

None of the participants used hearing aids, which was a requirement for participating in the study. The old and young adults did not differ with respect to their self-assessed visual acuity [$\chi^2(2) = 2.75, p > .25$], but they did differ with respect to their self-assessed hearing ability [$\chi^2(2) = 6.92, p < .05$; the old adults were underrepresented in the "very good" category] and health [$\chi^2(2) = 17.14, p < .01$; the old adults were underrepresented in the "very good" category and overrepresented in the "bad" category], and the old adults seemed happier with their lives than the young adults, although this difference just missed the criterion for statistical significance [$\chi^2(2) = 5.88, p = .05$]. The old adults were less well educated than the young adults (13 old adults had 9 years of schooling, 17 had 10 years, and 13 had 13 years, whereas 1 young adult had 10 years of schooling and the other 45 had 13 years). Finally, the old participants were more likely to use medication ($z = -5.48, p < .01$) and had poorer visual acuity on the visual acuity test ($z = -4.35, p < .01$).

Materials. The materials were identical to those used in Experiments 1A and 1B, with the following exceptions. For the digit span test, which preceded the experiment proper, extra lists were created that varied in sequence length from 2 to 18 numbers. For each sequence, the digits were sampled randomly from the set $\{1, 2, \ldots, 9\}$, with the restriction that two adjacent digits could not be identical. The length of the sequences was increased by one digit after every fourth list. The sampling procedure and presentation of these sequences were identical to the procedures used in the test phase. In the experiment proper, the length of the sequences that each participant had to recall corresponded to the participant's digit span.

Procedure. Prior to the experiment proper, the simple digit span of each participant was assessed. Except for the length of the sequences, the procedure of the digit span test was identical to that used in the sound-absent condition of the experiment. Testing began with sequences of two digits, with the length of sequences increased by one every four trials. Prior to each block of sequences of the same length, the participants were informed about the number of digits they would have to recall in the following set of four sequences. Testing ended when a participant failed to report correctly two or more of the four same-length sequences. Recall of a sequence was considered correct only when all digits were recalled in their accurate serial positions. Digit span was defined as the longest sequence correctly recalled on 50% of the trials.

After completion of this digit span test, the experiment proper began. The procedure was identical to that used in Experiment 1A, except that the sequence length of the to-be-recalled digit lists corresponded to the individual digit span.

Design. A 2 × 2 factorial design was used. Age group (old vs. young) was the quasi-experimental between-subjects variable, and irrelevant sound (present vs. absent) was the within-subjects variable. The dependent variable was participants' serial recall performance, which was transformed into a proportion correct score based on the number of trials completed in each condition and the number of digits presented in those trials. Given a total sample size of 91 ($N_{\text{old}} = 45$, $N_{\text{young}} = 46$) and $\alpha = .05$, an effect of size $f = 0.4$ (a large effect in terms of the conventions suggested by Cohen, 1988) could be detected for the age × irrelevant sound interaction with a probability of $1 - \beta = .97$.

Results

For the old adults, the distractor sounds were presented at a level that ranged from 62 to 79 dB(A), *Mdn* = 70. Four of the old participants reached the maximum sound level. The statistical conclusions reported below were not altered when those individuals were excluded from the analysis. For the young adults, the distractor sound level ranged from 51 to 70 dB(A), *Mdn* = 59. Sounds were played significantly louder for the old adults than for the young adults, as revealed by a *U* test ($z = -7.59$, $p < .01$).

The mean digit spans were 5.5 ($SD = 1.3$) and 6.6 ($SD = 1.2$) digits for the old and young adults, respectively. This difference was significant [$t(89) = 4.24$, $p < .01$, $\eta^2 = .17$]. Digit span ranged from 3 to 10 digits in the old adults and from 4 to 10 digits in the young adults.

For the test trials, the number of items correctly recalled in each of the irrelevant-sound conditions was transformed into a proportion correct score. Figure 3 illustrates the serial recall performance of both age groups in both irrelevant-sound conditions. A 2 × 2 repeated measures MANOVA with age (old vs. young) as a between-subjects variable and irrelevant sound (present vs. absent) as a within-subjects variable was performed on the proportion correct scores. The main effect of age group was not significant [$F(1,89) = 0.01$, $p = .94$, $\eta^2 < .01$], indicating that the span adjustment was successful. The irrelevant-sound effect, however, was even more pronounced than in Experiments 1A and 1B [$F(1,89) = 49.62$, $p < .01$, $\eta^2 = .36$]. This result supports our suspicion that age-specific floor effects, rehearsal strategy changes, or both could potentially have attenuated the irrelevant-sound effect in the preceding experiments. However, the interaction between age and irrelevant sound was still not significant [$F(1,89) = 0.38$, $p = .54$, $\eta^2 < .01$]: The old adults were no more impaired by the presence of the irrelevant sound than were the young adults. Follow-up *t* tests using the Bonferroni–Holm method of protecting against α error accumulation (Holm, 1979) showed that the irrelevant-sound effect was significant for both old adults [$t(44) = 4.42$, $p < .01$, $\eta^2 = .31$] and young adults [$t(45) = 5.58$, $p < .01$, $\eta^2 = .41$]. An additional analysis in which only those old adults above the median age for their group were included resulted in the same statistical conclusions as the first analysis.[4]

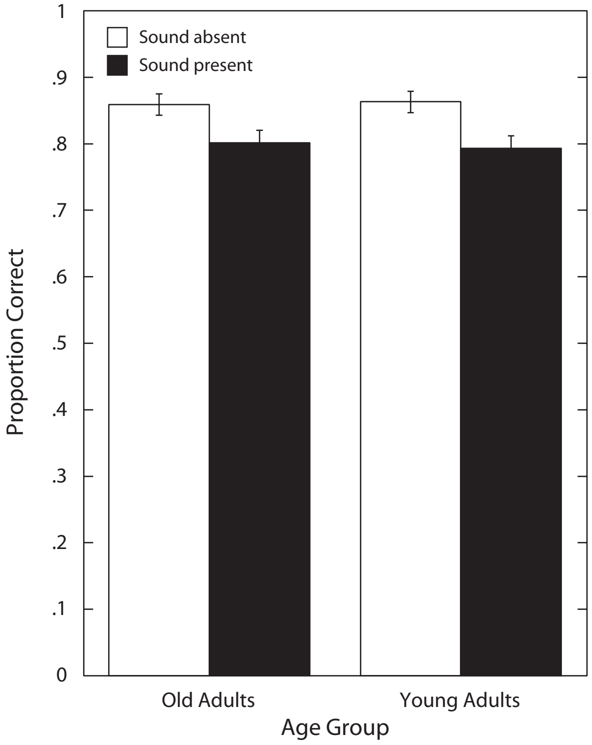

Figure 3. Proportions correct averaged across groups with different digit spans in Experiment 2, as a function of irrelevant-sound condition and age group. The error bars represent standard errors of the means.

Discussion

The results of Experiment 2 confirm once again that old and young adults are equally affected by irrelevant sound, even though in this experiment differences in hearing ability were taken into account and the difficulty of the serial recall task was adjusted to individual digit spans. The absence of a significant difference between age groups in the proportion correct scale of Experiment 2 indicates that the digit span adjustment was successful, so the difficulty of the serial recall task did not differ between groups. Therefore, it is unlikely that floor effects or differences in mnemonic strategy due to differential task demands had an influence on the size of the irrelevant-sound effect in this experiment.

As a side note, the age difference in digit span measures in the present experiment is in line with data from a meta-analysis that found reliable age differences in simple span tasks (Verhaeghen & Marcoen, 1993). As in the previous experiments, the lack of increased susceptibility to irrelevant sound among the old adults cannot be attributed to an absence of cognitive impairment, because they clearly differed from the young adults in digit span.

GENERAL DISCUSSION

The present series of experiments yielded a consistent pattern of results. First, old adults showed poorer performance than young adults in the serial recall tasks of Experiments 1A and 1B as well as in the digit span task of Experiment 2. Second, serial recall performance was impaired by irrelevant office sounds. Third, and most importantly, this impairment was of equal magnitude for both age groups. The present results thus replicate and extend previous reports of the absence of age differences in the size of the irrelevant-sound effect (Beaman, 2005; Belleville et al., 2003; Rouleau & Belleville, 1996). No age-specific irrelevant-sound effect was observed, even though the present experiments had more statistical power than previous studies have had. Experiment 1A had a statistical power of .94 to detect even a medium effect. Although the statistical power was smaller than this in Experiments 1B and 2, those experiments still had a power of at least .95 to detect large age-related effects. Furthermore, in all of our experiments, the sound level of the irrelevant auditory distractors was individually adjusted to the hearing abilities of the participants. Therefore, the absence of an age × irrelevant sound interaction throughout these experiments cannot be attributed to hearing deficits among old adults that masked an otherwise increased susceptibility to irrelevant sound. In Experiment 2, the number of the to-be-remembered items was also individually adjusted to match each participant's digit span, so that task difficulty was equated across age groups. Therefore, the interpretation of the data from this final experiment is not complicated by the possibility of floor effects. Likewise, our span-matching procedure ruled out age-specific differences in mnemonic strategies that might occur when the difficulty of a serial recall task differs between the old and young adults.

The short-term maintenance of short sequences of digits is a task that is thought to rely heavily on working memory. The differences between age groups in serial recall performance in Experiments 1A and 1B and in digit span in Experiment 2 thus reflect age-related differences in working memory functioning. According to the inhibitory deficit theory, age-related differences in working memory functioning, as reflected in a variety of span tasks, are determined by the presence of working memory interference in these tasks (see, e.g., Lustig, May, & Hasher, 2001). As a consequence, a reduction of interference should attenuate age-related differences in working memory performance, whereas manipulations that increase working memory interference should amplify such age-related differences. However, the present results showed age-related differences in working memory performance that were independent of the presence of interference from irrelevant sounds. Hence, our results are inconsistent with the claim of the inhibitory deficit theory that old adults are generally more vulnerable to working memory interference from environmental distraction (see, e.g., Lustig & Hasher, 2001).

The present results stand in contrast to the evidence showing that other populations with known differences in attentional control, such as young adults and children, also differ in the size of the irrelevant-sound effect (Elliott, 2002; Elliott & Cowan, 2005). The experimental procedure in those studies was very similar to that of Experiment 2 reported here. Thus, it seems that children do indeed have limited attentional control, but old adults do not. This interpretation is consistent with accumulating evidence of preserved inhibitory functioning in old adults. For example, a considerable body of research has now shown effects of the same size in old and young adults with the negative priming paradigm (Buchner & Mayr, 2004; Gamboz, Russo, & Fox, 2002; Verhaeghen & De Meersman, 1998a). Similarly, a meta-analysis has confirmed that age-related differences in Stroop interference disappear once cognitive slowing is taken into account (Verhaeghen & De Meersman, 1998b). The inhibitory deficit theory is also challenged by evidence of preserved inhibitory functioning during old age in many aspects of cognitive functioning, including language comprehension and production, memory, and attention (for reviews, see Burke, 1997; McDowd, 1997).

However, at first glance, the finding that old and young adults are equally susceptible to working memory interference may seem inconsistent with other studies that have reported age differences in the susceptibility to distraction. For instance, there are known age-related differences in the ability to ignore auditory distractors (e.g., competing speech) when trying to understand spoken target sentences (Barr & Giambra, 1990; Tun et al., 2002; Tun & Wingfield, 1999) and in the ability to ignore written distractor words when reading (Carlson et al., 1995; Connelly et al., 1991; Li et al., 1998). A number of differences in task characteristics between these tasks and the irrelevant-sound paradigm, however, could be responsible for these seemingly conflicting findings. For example, it has been previously suggested that age differences in the susceptibility to distraction are less likely to be found when the target and the distractors are easily distinguishable on the basis of salient perceptual cues (Hasher et al., 1999; Lustig, Hasher, & Tonev, 2001). This suggestion derives from visual selective attention tasks, in which target–distractor interference is reduced to the degree that targets and distractors can be easily distinguished. In contrast, in the irrelevant-sound paradigm, the acoustic distractors interfere *substantially* with the primary task of memorizing the to-be-remembered items, *even though* they are distinguished by modality and are thus very easy to distinguish on the basis of salient perceptual cues.

One way to explain the importance of the perceptual distinctiveness of targets and distractors in visual selective attention tasks is to note that age differences in such tasks may well occur at a perceptual level rather than in working memory. It has previously been argued that age differences in the ability to understand speech in noise may be due to sensory decline (Pichora-Fuller et al., 1995). Consistent with this interpretation, age differences in listening-in-noise tasks disappear with adequate adjustment for individual differences in hearing (Murphy, McDowd, & Wilcox, 1999; Schneider, Daneman, Murphy, & See, 2000; Schneider et al., 2002). A similar argument might apply to the visual reading-with-distraction task. The customary procedure of experiments using this task has been to present text that either is or is not interspersed with distractor words written in a different font style. Given the severe visual impairments associated with old age, older persons might well have greater difficulty discriminating target from distractor words at a sensory level. Such an interpretation is supported by the findings that age differences diminish when visual distractors are placed at predictable locations (Carlson et al., 1995) and that old adults are more likely than young adults to start vocalizing the distractor words when trying to read the target text (Dywan & Murphy, 1996).

Other factors that have been demonstrated to influence age differences in distractibility are the semantic content of the distractors and the semantic relatedness of target stimuli and distractors. Consider, for example, the finding from a listening-in-noise task that old adults', but not young adults', recall of target speech seems to be more disrupted by meaningful distractor speech than by either speech in an unfamiliar language or white noise

(Tun et al., 2002; Tun & Wingfield, 1999). Likewise, in reading-with-distraction tasks, old adults are more impaired than younger adults by written distractor words, especially when the distractor words are semantically related to the target text (see, e.g., Carlson et al., 1995; Connelly et al., 1991; Li et al., 1998). In the present experiments, the distractors had little semantic content, and the to-be-remembered digits and the to-be-ignored distractors bore little semantic relation to one another. Thus, one could ask whether an age-specific irrelevant-sound effect could be found with auditory distractors that were more meaningful than those in the present experiments and with to-be-remembered visual items and to-be-ignored auditory distractors that were semantically related. There are many reasons why the semantic content of distractors and the semantic relatedness between the target stimuli and the distractors might influence the degree to which distractors would interfere with a primary task. For example, the degree to which the distractors are meaningful and semantically related to the to-be-remembered items may be confounded with the perceptual distinctiveness between target stimuli and distractors. Besides, some of the alleged age-related differences in interference control may be attributable to age differences in source memory rather than in inhibitory capacity. For example, the finding that old adults are more likely than young adults to recall more inserted distractor words in a subsequent text comprehension or memory test (Carlson et al., 1995; Connelly et al., 1991; Li et al., 1998) may also be supported by poorer source memory in old adults (Bayen & Murnane, 1996), resulting in target–distractor confusions at the time of output. These confusions may be more likely when targets and distractors are more similar to each other.

Alternatively, one could assume that different inhibitory mechanisms, depending on particular task characteristics, are involved in the reduction of working memory interference; some of these mechanisms could be impaired in old age, others might not be. Rouleau and Belleville (1996) referred to an idea of Connelly and Hasher (1993) when they explained their absence of an age × irrelevant sound interaction by assuming that the "phonological" inhibition of old adults was intact and only the "semantic" inhibition was impaired. As Beaman (2005) has already discussed in detail, it is not commonly accepted that an irrelevant sound reflects phonological coding. In addition, proposing differentially impaired inhibitory mechanisms based entirely on the presence or absence of age-related differences in certain tasks bears the danger of tautology. Nevertheless, it seems that the inhibitory deficit theory has to be adjusted to account for the finding of preserved resistance to working memory interference in old adults in the irrelevant-sound paradigm.

Instead of postulating different inhibitory mechanisms, some of which are impaired and some not, one could of course argue that the irrelevant-sound effect is not subject to inhibitory control at all. In fact, Baddeley's modular working memory model (Baddeley & Salamé, 1986; Salamé & Baddeley, 1982) and Jones's object-oriented episodic record model (Jones & Macken, 1993; Jones et al., 1993) currently do not specify attention as a critical component in their explanations of the irrelevant-sound effect (but see Baddeley & Larsen, 2003; Hughes & Jones, 2003). However, we think that there is strong evidence for attentional modulation of the irrelevant-sound effect (Buchner & Erdfelder, 2005; Buchner et al., 2006; Buchner et al., 2004; Elliott, 2002; Gisselgård et al., 2003). Besides, it is one of the central claims of the inhibitory deficit theory that inhibitory attentional mechanisms play *the* essential role in the ability to perform a task in the presence of irrelevant information. From the real-world examples used to illustrate the inhibitory deficit theory in our introduction, it is quite obvious that old adults should be more distracted than young adults by irrelevant auditory noise when performing a visual primary task (Lustig, Hasher, & Tonev, 2001). However, these predictions were not confirmed by the outcomes of the present experiments.

In summary, the results of the present experiments replicate previous results (Beaman, 2005; Belleville et al., 2003; Rouleau & Belleville, 1996) by showing that old and young adults are equally susceptible to auditory distraction when performing a serial recall task. By increasing the statistical power of our experiments, adjusting the sound level of the auditory distractors to the hearing capabilities of the participants, and adjusting the number of to-be-remembered items to the digit spans of the participants, we could exclude the explanations that our results derived from a lack of statistical power, from hearing deficits among old adults, or from differential task difficulty. This finding of equal working memory interference between old and young adults challenges the assumption of the inhibitory deficit theory that old adults are generally susceptible to working memory interference due to environmental distraction.

AUTHOR NOTE

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NOTES

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

2. 57 old adults were included in the analysis, 37 of whom were female. They ranged in age from 65 to 86 years (M = 70.3, SD = 6.0). The main effects of age group [$F(1,160) = 135.09$, $p < .01$, $\eta^2 = .46$], irrelevant sound [$F(1,160) = 29.00$, $p < .01$, $\eta^2 = .15$], and serial position [$F(8,153) = 203.17$, $p < .01$, $\eta^2 = .91$] were all significant. The most relevant interaction, between age group and irrelevant sound, was not significant [$F(1,160) = 0.10$, $p = .76$, $\eta^2 < .01$]. The interaction between age and serial position still reached significance [$F(8,153) = 12.59$, $p < .01$, $\eta^2 = .40$]. The interaction between irrelevant sound and serial position failed to reach significance [$F(8,153) = 1.70$, $p = .10$, $\eta^2 = .08$]. This was also true for the three-way interaction between age, irrelevant sound, and serial position [$F(8,153) = 0.52$, $p = .84$, $\eta^2 = .03$].

3. A total of 23 old adults were included in this analysis, 15 of whom were female. They ranged in age from 67 to 80 years (M = 72.0, SD = 4.3). The main effects of age group [$F(1,63) = 39.94$, $p < .01$, $\eta^2 = .39$], irrelevant sound [$F(1,63) = 19.05$, $p < .01$, $\eta^2 = .23$], and serial position [$F(8,56) = 134.79$, $p < .01$, $\eta^2 = .95$] were all significant. The most relevant interaction, between age group and irrelevant sound, was not significant [$F(1,63) = 0.34$, $p = .56$, $\eta^2 < .01$]. The interaction between age and serial position still reached significance [$F(8,56) = 3.91$, $p < .01$, $\eta^2 = .36$], and the interaction between irrelevant sound and serial position [$F(8,56) = 0.63$, $p = .75$, $\eta^2 = .08$] and the three-way interaction between age, irrelevant sound, and serial position [$F(8,56) = 0.68$, $p = .71$, $\eta^2 = .09$] still failed to reach significance.

4. A total of 23 old adults were included in this analysis, 20 of whom were female. They ranged in age from 67 to 80 years (M = 71.6, SD = 4.1). This time, the main effect of age group was not significant [$F(1,67) = 0.05$, $p = .46$, $\eta^2 < .01$], as a result of the span adjustment. The main effect of irrelevant sound was significant [$F(1,67) = 52.77$, $p < .01$, $\eta^2 = .44$]. The most relevant interaction, between age group and irrelevant sound, was again not significant [$F(1,67) = 0.55$, $p = .46$, $\eta^2 < .01$].

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