Older or lower educated individuals may be less able than younger or higher educated individuals to inhibit irrelevant speech when learning new visual information. In Experiment 1, we investigated the effects of age (four groups), educational attainment (low or high), and verbal noise (spoken words or silence) on word-learning performance in 230 individuals aged 24 to 76 years. Performance was negatively affected by age, lower education, and irrelevant speech, but there were no interactions between age group and noise condition. In Experiment 2, we increased the difficulty of the word-learning task by using both irrelevant speech and a short interstimulus interval (2 or 0.5 s). Age differences became more pronounced as the result of the simultaneous occurrence of irrelevant speech and a short interstimulus interval. This suggests that older individuals may need more time than younger individuals to learn new information in noisy environments.

Older people frequently complain about being distracted by environmental noise, such as other people talking or radio sound, when they are occupied with reading or memorizing information. In particular, irrelevant speech is one of the most common sources of complaint by people in a broad age range (Kjellberg, Landstrom, Tesarz, Soderberg, & Akerlund, 1996). From a theoretical perspective, it can be expected that the performance of older adults on verbal learning tasks is more sensitive than that of younger people to interference caused by irrelevant speech. The ability to suppress noise might involve inhibitory mechanisms (Dempster & Brainerd, 1995), which may be less efficient in aging individuals (Hasher & Zacks, 1988). A major function attributed to these inhibitory processes is to prevent irrelevant material from accessing working memory and to deactivate any such material that enters the information stream. It has been proposed that various age-related differences in cognitive performance might be due to defective inhibitory processes (Mc Dowd, Oseas-Kreger, & Filion, 1995).

Researchers have frequently assessed the relationship between working memory and inhibition by examining the effect of irrelevant speech on the learning of visually presented information by young adults (LeCompte, 1994; LeCompte, Neely, & Wilson, 1997). To our knowledge, only three earlier studies have compared the effect of irrelevant speech on this type of learning between older and younger age groups (Beaman, 2005; Enmarker, 2004; Rouleau & Belleville, 1996). These studies, which involved rather small samples of one young group and one old group, did not show a disproportionate performance decrement in older adults as a result of irrelevant speech during the serial learning of digits (Beaman, 2005; Rouleau & Belleville), during a complex counting task (Van Gerven, Meijer, Vermeeren, Vuurman, & Jolles, in press), or during the learning of a text, sentences, faces, and names (Enmarker, 2004). This absence of an Age by Noise interaction is in line with the results of a study by Beaman (2004), which demonstrated that the performance of students with a low working-memory span is not more disrupted by irrelevant speech than is the performance of students with a high working-memory span in serial or free recall. When this is extended to older adults, who generally have less working-memory capacity than younger persons, no disproportionate performance decrement as a result of irrelevant speech would be expected.

The absence of an Age by Noise interaction could also be due to the type of memory task that is used. In the aforementioned serial recall studies (Beaman, 2005; Rouleau & Belleville, 1996), participants were required to memorize the order of a short series of digits, which were essentially meaningless (LeCompte, 1999). Because earlier research suggests that older adults have less access to semantic memory (Petros, Zehr, & Chabot, 1983) and less recall of words as a result of semantic processing (Eysenck, 1974), irrelevant speech might affect their learning of meaningful material. In addition, single words, which are commonly used as irrelevant speech (e.g., LeCompte, 1994; LeCompte et al., 1997), are more controllable in terms of prosody, timing, and similarity to target words (e.g., number of letters and syllables) than are other sources of noise such as babble or orally presented text that have been used in previous studies (Enmarker, 2004; Rouleau & Belleville; Van Gerven et al., in press). In contrast to the earlier studies using serial recall of digits and less controllable sources of noise, our aim in the first experiment in the present study was to examine the effect of spoken irrelevant words during the learning phase of a visual word-learning task on recall in different age groups. In this way, we can sort out whether the previously found absence of Age by Noise interaction was due to the type of memory task or noise source, or whether older adults are truly as able as younger adults to inhibit irrelevant speech.
Besides environmental conditions, such as the presence of irrelevant speech, task-related factors might also influence age-related differences in word-learning performance. As was pointed out by Kane, Hasher, Stoltzus, Zacks, and Connelly (1994), it is possible that exposure durations of relevant and irrelevant stimuli in typical negative priming experiments generally are too short for older adults to encode whatever critical information is needed to engage inhibitory mechanisms. Similarly, a short study time may impede the inhibition of irrelevant speech, which may result in reduced word-learning performance, especially in older adults, who generally process information more slowly than do younger adults (Salthouse, 1996). It would therefore be of interest to know whether irrelevant speech is harder to suppress by older adults when words to be learned are presented more quickly. In the current study, we examined this in a second experiment in which we shortened the interstimulus interval (ISI) under conditions of irrelevant speech.

In addition to environmental and task-related conditions, certain individual characteristics, such as education, can moderate cognitive functioning in later adulthood. People with low educational attainment experience more age-related cognitive decline than do people with high educational attainment (Bosma, Van Boxtel, Ponds, Houx, & Jolles, 2003). There are several arguments to support this protective effect of education. First, continuous mental stimulation associated with a high level of education may have a positive effect on neural growth and the complexity of neural networks (Coffey, Saxton, Ratcliff, Bryan, & Lucke, 1999). Second, higher educated persons might have an active lifestyle that is associated with a smaller risk of cognitive dysfunction (Gold et al., 1995). Third, educational experience may provide reserve capacity in the form of a more elaborate set of basic skills or cognitive strategies (Stern, 2002). Education, which leads to proficient language use, could particularly influence age differences in verbal learning. In contrast to serial recall of digits, word learning involves the use of semantic and other encoding strategies, which may be used more in highly educated persons than in lower educated persons. Moreover, because researchers have found age differences in inhibitory function, as derived from Stroop test performance, to be smaller in higher educated persons (Van der Elst, Van Boxtel, Van Breukelen, & Jolles, 2006), the potentially greater effect of irrelevant speech on older adults’ word-learning performance might be attenuated by higher education. Our third purpose in this study was therefore to examine how education affects performance under conditions with or without irrelevant speech (Experiment 1) and with a short or long ISI combined with irrelevant speech (Experiment 2).

**Experiment 1**

**Effects of Irrelevant Speech**

**Methods**

**Participants**

We recruited participants from the Registration Network of Family Practices (Metsemakers, Hoppener, Knottnuerus, Kocken, & Limonard, 1992) who took part in the Maastricht Aging Study (Jolles, Houx, Van Boxtel, & Ponds, 1995; Van Boxtel et al., 1998). This prospective study on the biological and sociodemographic determinants of cognitive aging involves 1,823 healthy individuals who are between the ages of 24 and 81 years. Participants were stratified for sex, two levels of occupational achievement, and age (12 groups; ranging from 25 ± 1, 30 ± 1, 35 ± 1, etc., to 80 ± 1 years). None of the participants had documented medical conditions known to interfere with normal cognitive functioning (e.g., dementia, mental retardation, and cerebrovascular pathology) at intake. We used the baseline data of 221 healthy individuals aged 24 to 77 years for the present study.

**Design**

We chose a 4 × 2 × 2 cross-sectional design with four consecutive age groups, two noise conditions, and two educational levels. The Visual Verbal Learning Test (VVLT) was used to measure memory performance. We randomly assigned the participants to either a silent condition (n = 109) or a noise condition (n = 112). Noise was used as a between-subject variable in order to avoid carryover effects caused by repeated testing.

**Measures**

Characteristics of the participants.—Age was used as a categorical variable. We collapsed 11 discrete age groups into 4 age groups, that is, young (24–37 years), young middle-aged (39–51 years), old middle-aged (54–66 years), and old (69–77 years).

We assessed level of education by classifying formal schooling according to a system often used in the Netherlands (de Bie, 1987), which is comparable with the International Standard Classification of Education (UNESCO, 1976). Educational level was scored in eight ordinal categories, ranging from unfinished primary school to university education. For the present study, we recoded education into two levels: low, primary education, lower vocational education, and intermediate secondary education; and high, intermediate vocational education, secondary education, higher vocational education, higher secondary education, and university. The low level of education was equivalent to a maximum of 12 years of education. The high level was equivalent to a minimum of 13 years.

We measured verbal intelligence with the 20-item multiple-choice Vocabulary subtask of the Groningen Intelligence Test (Luteijn & Van der Ploeg, 1983).

We assessed hearing acuity to control for interindividual differences in perceiving the auditorily presented information. Because age differences in speech perception are only minimal after correction for age-related differences in pure-tone sensitivity (Heller, 1992; Lutman, Gatehouse, & Worthington, 1991; Sommers, 1997), we considered the assessment of pure-tone sensitivity to be an adequate approximation of speech perception in aging individuals. An audiometric test under standard laboratory conditions was carried out by measuring pure-tone air-conduction thresholds (in decibels) for each ear at 0.5, 1, 2, and 4 kHz, using a screening audiometer (Interacoustics AS7, Denmark). We expressed hearing acuity as the average hearing threshold at 1, 2 and 4 kHz for the best ear (Davis, 1995).
Table 1. Participant Characteristics per Age Group (in Years) for Experiment 1

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Young (24–37)</th>
<th>Middle-Aged (39–51)</th>
<th>Middle-Aged (54–66)</th>
<th>Old (69–77)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>58</td>
<td>59</td>
<td>64</td>
<td>38</td>
</tr>
<tr>
<td>Age M (SD)</td>
<td>30.4 (4.4)</td>
<td>45.3 (4.1)</td>
<td>60.4 (3.9)</td>
<td>72.8 (2.6)</td>
</tr>
<tr>
<td>Male-to-female ratio</td>
<td>39/59</td>
<td>30/29</td>
<td>33/31</td>
<td>18/20</td>
</tr>
<tr>
<td>Low or high education</td>
<td>16/42</td>
<td>28/31</td>
<td>46/18</td>
<td>24/14</td>
</tr>
<tr>
<td>Educational level M (SD)</td>
<td>4.3 (1.8)</td>
<td>3.9 (1.8)</td>
<td>2.9 (1.4)</td>
<td>2.8 (1.7)</td>
</tr>
<tr>
<td>Vocabulary (SEM)</td>
<td>12.6 (0.4)</td>
<td>13.7 (0.4)</td>
<td>14.1 (0.4)</td>
<td>13.9 (0.5)</td>
</tr>
<tr>
<td>Hearing acuity (SD)</td>
<td>6.9 (3.4)</td>
<td>9.5 (5.9)</td>
<td>16.0 (11.8)</td>
<td>24.5 (11.9)</td>
</tr>
</tbody>
</table>

Notes: SD = standard deviation; SEM = standard error of mean.

**Task and dependent variables.**—The VVLT, an adaptation of a test originally devised by Rey (1964), measures intentional learning and verbal memory (Brand & Jolles, 1985). We presented 15 monosyllabic words that refer to objects, one after another, at the center of a computer screen in lowercase letters of a Times-like font. The height of the letters on the screen was approximately 20 mm. Participants were seated in front of a 17-in. (43-cm) monitor at a normal viewing distance of approximately 25 in. (60 cm). Before testing, participants were screened for visual difficulties by asking whether they could, if necessary with glasses, read a newspaper. We excluded persons with obviously reduced eyesight. The words were presented for 1 s, with 2 s between the disappearance of one word and the arrival of the consecutive word. In the noise condition, we used a male voice to present 15 other monosyllabic words that refer to objects for a maximum of 1 s. The words were presented by means of loudspeakers connected to a computer. Each auditory word started 500 ms after the appearance of a visually presented word. After presentation, the participants were asked to recall as many visually presented words as possible in any order. This procedure was repeated four times. When the fifth trial was completed, we administered a fixed battery of cognitive tests, not involving the learning of verbal material, for approximately 20 min. After this delay—and unexpectedly for the participants—delayed recall was measured. The following dependent variables were used in the present study: we used Trial 1 as a measure of short-term memory (Vakil & Blachstein, 1993); because ceiling effects are often observed in the VVLT, we used the total number of words recalled over the first three trials as a measure of immediate memory (Van der Elst, Van Boxtel, Van Breukelen, & Jolles, 2005); and we used the number of words recalled after 20 min as a measure of delayed recall.

**Data Analysis**

We analyzed differences in educational level and sex between age groups by using chi-square tests. We used two 4 × 2 analyses of variance to analyze differences between four age groups and two educational levels in verbal intelligence and in hearing acuity. To assess main effects of age (young, young middle-aged, old middle-aged, and old), noise (quiet and speech), education (low and high), and all possible interactions between these factors, we carried out a 4 × 2 analysis of covariance on performance on the first trial, immediate recall, and delayed recall. We included sex and hearing acuity as covariates. We also conducted the analyses without hearing acuity as a covariate (sex remained covariate) in order to rule out the possibility that the effects of hearing acuity reduced the variance explained by age. We analyzed statistically significant main effects of age by means of repeated contrasts with Bonferroni correction in which the alpha level, $p = 0.05$, was divided by the number of comparisons. We investigated significant interactions by means of simple contrasts with Bonferroni correction. Post hoc power analyses on the available number of participants, using a medium critical effect size of 0.15 and an alpha level of $p = 0.05$, resulted in a power of 0.99 (Buchner, Faul, & Erdelder, 1992).

**RESULTS**

The characteristics of the sample are shown in Table 1. We used the data of 219 individuals in the analyses, because 2 participants did not have a hearing acuity measure. As expected because of the stratification procedure, the age groups were comparable with respect to sex. The older individuals were significantly less educated than the younger individuals: $\chi^2(3, N = 219) = 26.3, p < .01$. The four consecutive age groups did not differ significantly on vocabulary, $F(3, 211) = 2.5, p = .06$, and the vocabulary scores of the higher educated individuals ($M = 15.3$) were significantly higher than those of the lower educated individuals ($M = 11.8$), $F(1, 211) = 68.0, p < .01$. Hearing acuity differed significantly between age groups, $F(3, 211) = 29.2, p < .01$, but not between educational levels.

**Effects of Age and Irrelevant Speech on Word-Learning Performance**

We present the mean performance (number of words recalled) on Trial 1, immediate recall, and delayed recall per age group and noise condition in Figure 1. We found main effects of age on all dependent measures, indicating that the older participants outperformed the younger participants: $F(3, 201) = 3.4, p = .019$, partial $\eta^2 = .049$ ($Ms = 5.4, 5.0, 4.6$, and 4.1 for each consecutive age group, respectively); immediate recall, $F(3, 201) = 6.1, p < .01$, partial $\eta^2 = .084$ ($Ms = 24.1, 23.6, 21.4$, and 19.1); and delayed recall, $F(3, 201) = 3.8, p = .011$, partial $\eta^2 = .056$ ($Ms = 10.2, 9.7, 8.7$, and 7.8). None of the contrasts between the consecutive age groups were significant. We also found main effects of noise on all dependent measures, indicating that performance was better in the quiet condition than in the noise condition: $F(1, 211) = 56.7, p < .01$, partial $\eta^2 = .22$ ($Ms = 5.7$ and 3.9 for performance in quiet and noise conditions, respectively); immediate recall, $F(1, 201) = 72.7, p < .01$, partial $\eta^2 = .264$ ($Ms = 25.2$ and 18.9); and delayed recall, $F(1, 201) = 29.4, p < .01$, partial $\eta^2 = .126$ ($Ms = 10.3$ and 7.9). We found no Age × Noise interactions on Trial 1, $F(3, 201) = .86, p = .46$; immediate recall, $F(3, 201) = .49, p = .69$; and delayed recall, $F(3, 201) = 2.0, p = .11$. This finding indicated that the recall of the older adults was not more affected by irrelevant speech than was the recall of the younger adults. Hearing acuity did not significantly affect memory performance, with results being essentially the same regardless of whether hearing acuity was included in or excluded from the model.

**Effects of Education in Relation to Age and Irrelevant Speech on Word-Learning Performance**

Figure 2 shows the mean performance (number of words recalled) on Trial 1, immediate recall, and delayed recall...
presented per noise condition and educational level. We found main effects of education on all dependent measures, indicating that higher educated participants performed better than lower educated participants: Trial 1, $F(1, 201) = 3.9, p = .05$, partial $\eta^2 = .019$ ($M_s = 4.5$ and 5.0 for low and high education, respectively); immediate recall, $F(1, 201) = 12.6, p < .01$, partial $\eta^2 = .061$ ($M_s = 20.7$ and 23.4); and delayed recall, $F(1, 201) = 20.2, p < .01$, partial $\eta^2 = .094$ ($M_s = 8.1$ and 10.1). We also found one statistically significant interaction, namely, between irrelevant speech and education on Trial 1, $F(1, 201) = 6.1, p = .014$, partial $\eta^2 = .03$. We analyzed this interaction per condition to detect differences between educational levels. The higher educated participants outperformed the lower educated participants when there was no speech interference, $F(1, 201) = 11.9, p < .01$, but not when there was speech interference. We found no Age $\times$ Education (values of $F < 1.5, p > .25$) and Age $\times$ Noise $\times$ Education (values of $F < 2, p > .13$) interactions.

Discussion

The present study is one of the few studies to assess the effect of irrelevant speech on word learning. In previous research, this effect was mainly studied on serial recall. The present experiment clearly demonstrates that irrelevant speech consisting of single words interferes with word learning. The results showed no Age by Speech interactions, indicating that the effects of noise on verbal learning performance are equal for older and younger adults. Higher educated individuals outperformed lower educated individuals on Trial 1 only in the quiet condition, which does not support the hypothesis that a high level of education attenuates the effect of irrelevant speech. Apparently, short-term memory, as measured in Trial 1, is especially vulnerable to the negative effects of irrelevant speech: Individuals with better cognitive abilities (i.e., higher educated persons) perform at the same level as individuals with poor cognitive abilities when there is background noise.

In the light of the results of this first experiment, which demonstrated no increased vulnerability to interference from irrelevant speech in older adults, we found it important to study verbal learning under an even more restrictive learning condition. In daily life, there are numerous situations in which information has to be processed very quickly, attention has to be divided between multiple sources of information, and irrelevant stimuli have to be ignored. Controlled experimental procedures to examine age differences in cognitive performance are generally easier than these demanding situations in daily life. In relatively simple test situations, there is more
opportunity for older adults to use compensatory strategies, which may obscure the potential cognitive vulnerabilities in older adults. We addressed this issue in Experiment 2.

**EXPERIMENT 2**

**COMBINED EFFECTS OF IRRELEVANT SPEECH AND INTERSTIMULUS INTERVAL**

In this second experiment, we aim to increase the difficulty of the VVLT in an experimentally controlled way in order to mimic the complexity of an everyday situation to test whether an age-related decrease in performance could be demonstrated. We accomplished this by varying the ISI, which was either long (i.e., 2 s) or short (i.e., 0.5 s). Our main question was whether age differences in recall would be greater with a short ISI than with a long ISI after a learning phase with irrelevant speech.

**METHODS**

**Participants**

For the second experiment, we reused the data of the 112 participants that took part in the noise condition of Experiment 1 for the ISI condition with 2 s. We recruited 105 other healthy participants aged 24 to 77 years from the Maastricht Aging Study for the ISI condition with 0.5 s. See Table 2 and the Participants section of Experiment 1 for further details.

**Design**

Again, we chose a $4 \times 2 \times 2$ cross-sectional design with four consecutive age groups, two ISI conditions, and two educational levels. We used the same VVLT as in Experiment 1. We assigned the participants to either a condition with an ISI of 2 s or a condition with an ISI of 0.5 s. We combined both...
ISI conditions with irrelevant speech; we included no quiet condition. We used the ISI, defined as the duration in seconds between the disappearance of one word and the arrival of the consecutive word, as a between-subject variable in order to avoid carryover effects caused by repeated testing.

Measures

Characteristics of the participants.—We assessed age, education, hearing acuity, and vocabulary in the same way as in Experiment 1.

Task and dependent variables.—We used the same VVLT and dependent variables as in the noise condition of Experiment 1. We presented the visual words for 1 s with a 2-s or 0.5-s ISI. As in Experiment 1, we presented the auditory words for a maximum of 1 s, starting 500 ms after the onset of the visually presented words in both ISI conditions.

Data Analysis

We carried out a 4 × 2 × 2 analysis of covariance over the first trial, immediate recall, and delayed recall to assess main effects of age (young, young middle-aged, old middle-aged, and old), ISI (2 and 0.5 s), education (low, high), and all possible interaction effects between these factors. Post-hoc power analyses on the available number of participants using a medium critical effect size of 0.15 and an alpha level of $p = 0.05$ resulted in a power of 0.99. Otherwise, our data analysis was the same as in Experiment 1.

RESULTS

The characteristics of the sample are shown in Table 2. We used the data of 214 individuals in the analyses, because 3 participants did not have a hearing acuity measure. The age groups were comparable with respect to sex. The older participants were significantly less educated than the younger participants, $\chi^2 (3, N = 214) = 38.8, p < .01$. The four consecutive age groups did not differ on vocabulary, $F(3, 206) = 2.20, p = .08$. The vocabulary scores of the higher educated persons were higher than those for the lower educated persons, $F(1, 206) = 67.4, p < .01$ ($Ms = 11.9$ and $15.3$). Hearing acuity differed significantly between age groups, $F(3, 206) = 40.2, p < .01$, and educational levels differed on hearing acuity too, $F(1, 206) = 10.9, p < .01$ ($Ms = 16.1$ and $12.3$ for low and high education, respectively).

![Figure 3](https://example.com/figure3.png)

Figure 3. Mean performance as a function of age and ISI: (a) Trial 1, (b) immediate recall, and (c) delayed recall. Error bars represent standard errors of the mean.
Effects of Age and ISI on Word-Learning Performance With Irrelevant Speech

In Figures 3(a), 3(b), and 3(c), the mean performance (number of words recalled) is presented per age group and ISI. We found main effects of age on immediate recall, $F(3, 196) = 5.4, p < .01$, partial $\eta^2 = .076$ ($Ms = 21.3, 19.0, 17.9$, and 15.5 for each consecutive age group, respectively) and delayed recall, $F(3, 196) = 2.9, p = .033$, partial $\eta^2 = .044$ ($Ms = 9.1, 7.9, 7.4$, and 6.4), indicating that the performance of the older adults was worse than that of the younger adults. None of the contrasts between the consecutive age groups were significant. We found a main effect of ISI only on Trial 1: Performance was better with the longer ISI than with the shorter ISI, $F(1, 196) = 8.2, p < .01$, partial $\eta^2 = .040$ ($Ms = 3.9$ and 3.2). There was a significant interaction between age and ISI on delayed recall, $F(3, 196) = 3.5, p = .017$, partial $\eta^2 = .050$. We analyzed this interaction per age group. Performance in the condition with the short ISI was worse than that in the condition with the long ISI only in the oldest age group, $F(3, 31) = 11.6, p < .01$. In other age groups, we found no effect of ISI (values of $F < 1.4$, $p > .25$). We found a trend to a significant interaction between ISI and age on immediate recall, $F(3, 196) = 2.3, p = .079$, partial $\eta^2 = .034$. This indicates a similar pattern, namely that the performance of older adults was worse than that of younger adults in the short ISI condition with irrelevant speech. Hearing acuity did not significantly affect memory performance. When we performed analyses without hearing acuity in the model, results remained the same.

Effects of Education in Relation to Age and ISI on Word-Learning Performance With Irrelevant Speech

The higher educated participants outperformed the lower educated participants only on delayed recall, $F(1, 196) = 4.9, p = .028$, partial $\eta^2 = .024$ ($Ms = 8.3$, and 7.1). We found a three-way Age $\times$ ISI $\times$ Education interaction on Trial 1, $F(3, 196) = 2.8, p = .042$, partial $\eta^2 = .041$. We analyzed this interaction per educational level to detect Age $\times$ ISI interactions. We found a significant Age $\times$ ISI interaction in the higher educated group, $F(3, 85) = 4.1, p < .01$, whereas we found no such interaction in the lower educated group. Figure 4 shows that, in the higher educated group, the youngest participants performed better with the short ISI than with the long ISI, whereas this pattern was reversed in
older participants. We found no Age × Education (values of $F < 1$, $p > .35$) and ISI × Education (values of $F < 1.5$, $p > .2$) interactions.

**Effects of Age, ISI, and Education on Intrusions of Irrelevant Spoken Words**

We also recorded and used the total number of words from the auditory distracter list recalled over the five learning trials (immediate recall intrusions) and the number of words from the auditory distracter list recalled during delayed recall (delayed recall intrusions) as dependent variables. We used two univariate analyses of variance with the covariates of hearing acuity and sex to analyze differences between age groups, ISIs, and educational levels. In Figure 5, the total number of words from the auditory distracter list recalled over the five learning trials is presented per age group and ISI. There was a main effect of age on immediate recall intrusions, $F(3, 195) = 9.5, p < .01$, partial $\eta^2 = .13$, and on delayed recall intrusions, $F(3, 195) = 2.8, p = .04$, partial $\eta^2 = .04$ ($M$s $= 0.90, 0.3, 0.5,$ and 0.3). This indicates that the number of intrusion errors increased with age. We found a main effect of ISI in immediate recall intrusions, $F(3, 195) = 11.6, p < .01$, partial $\eta^2 = .06$, indicating that the number of intrusions was larger in the condition with short ISI. In addition, a significant Age × ISI interaction on immediate recall intrusions, $F(3, 195) = 2.9, p = .035$, partial $\eta^2 = .04$, indicated that the difference in intrusions between the ISI conditions became larger with age. We also found an Age × ISI × Education interaction on immediate recall intrusions, $F(3, 195) = 4.6, p < .01$, partial $\eta^2 = .07$. In the higher educated group, the difference in intrusions between the ISI conditions became larger with age from young age on, but this difference was gone in the oldest participants, whereas in the lower educated group, the difference in intrusions between the ISI conditions became larger with age mainly from middle age on and remained in the oldest group. There were no main effects of education, or Age × Education and ISI × Education interactions (values of $F < 1.5, p > .2$).

**DISCUSSION**

Age differences in the performance on delayed recall were larger in a short relative to a long ISI condition with irrelevant speech. One interpretation is that the efficiency of information processing is compromised in older adults, especially when time is a constraint. Another interpretation might be that irrelevant stimuli that are presented more quickly are harder to suppress and thus should have an increasing effect on performance as inhibitory abilities decline. The finding that age differences in intrusion errors were also larger in the short relative to the long ISI condition substantiates this interpretation.

The Age by ISI by Education interaction on Trial 1 suggests that there were age differences in the low education group regardless of the ISI that was used. In contrast, age differences were only observed in the high education group when the short ISI was used. This suggests that education protects against age-related cognitive change, but that its protective power reaches a limit when the tasks demands are increased.

**GENERAL DISCUSSION**

A main outcome of Experiment 1 is that irrelevant speech interferes with word learning across all age groups. The results of the few previous studies that investigated effects of irrelevant speech on free recall of 16 words are equivocal. Whereas Neely and LeCompte (1999) did find an effect of irrelevant single words, researchers found no effects of irrelevant nonwords (LeCompte, 1994; Salame & Baddeley, 1990) and background conversation (Knez & Hygge, 2002). The failure to find an effect of irrelevant speech in three of these four studies might be due to the selection of relatively young university students. By definition, students have a high level of education, whereas the present study included people with high and low levels of education. Although the current findings did not show that people with high education experienced less interference from irrelevant speech than did people with low education, the results clearly demonstrate that higher educated individuals had a better memory performance. Memory performance may be more vulnerable to irrelevant speech interference at low memory ability levels (Enmarker, 2004).

The results of Experiment 1 showed no Age by Noise interaction. Thus, the effects of irrelevant speech on verbal learning performance are equal for older and younger adults. These results contradict those of other studies reporting inhibition deficits in aging. This discrepancy may be due to dif-
ferences in research paradigms. In contrast to the present study, in which relevant information was presented through the visual modality and irrelevant information was presented through the auditory modality, most studies showing inhibitory deficits in older people involved the presentation of relevant and irrelevant stimuli within the same modality.

An advantage of the present paradigm above paradigms in which targets and distractors are both presented auditorily is that any age-related differences in performance can be attributed mainly to cognitive deficits rather than to perceptual deficits. Although there is extensive evidence that noise affects speech perception (Murphy, McDowd, & Wilcox, 1999; Pichora-Fuller, Schneider, & Daneman, 1995) and short-term memory performance (Murphy, Craik, Li, & Schneider, 2000) more in older than in younger persons, these age-related deficits may be a function of hearing loss instead of decreased ability to inhibit irrelevant stimuli (Humes & Christopherson, 1991; Schneider, Daneman, Murphy, & Kwong See, 2000; Schneider, Daneman, & Pichora-Fuller, 2002). Older adults may have more difficulty with noise because they do not hear the target stimulus as well as younger adults do.

The discrepancy between the results obtained with the present paradigm and paradigms in which targets and distractors are both presented visually may be due to the assessment of different specialized inhibitory subsystems, of which only some are affected by aging. Age-related differences in visual selective attention have been explained in terms of greater vulnerability to distraction during reading (Connelly, Hasher, & Zacks, 1991), a weaker suppression effect in negative priming experiments (Connelly & Hasher, 1993; Hasher, Stoltzfus, Zacks, & Rypma, 1991; Kane et al., 1994; Stoltzfus, Hasher, Zacks, Ulivi, & Goldstein, 1993), and more sustained activation of considered but rejected sentence completions (Hartman & Hasher, 1991) and passage interpretations (Hamm & Hasher, 1992) in older adults. The results of these studies indicate that older adults are less able to inhibit the identity or meaning of irrelevant verbal material (lexicosemantic inhibition). In contrast, the general explanation for the irrelevant speech effect is that the interference caused by irrelevant speech is exclusively due to perceptual or phonological characteristics of speech. The phonological store hypothesis (Salamé & Baddeley, 1982) proposes the existence of a store that holds information coded at a phonological level; irrelevant speech has direct access to this store and may interfere with retention of the visual information that is recoded into a phonological representation (Baddeley, 2003; Larsen & Baddeley, 2003). Therefore, the results reported here suggest that phonological inhibition, in contrast to lexicosemantic inhibition, is preserved in older people, at least under unconstrained conditions. Thus, inhibitory capacity is not a single function that is generally affected by the aging process (Kramer, Humphrey, Larish, Logan, & Strayer, 1994). Interestingly, the present results demonstrate that older participants report more irrelevant spoken words than younger participants. This is in line with a study by Beaman (2004) in which it was demonstrated that students with a low working-memory span are also more likely to report the contents of irrelevant speech. This suggests that persons with efficient working-memory capacity, that is, younger persons, are less aware of the irrelevant or unattended stream, because they have more effectively inhibited the irrelevant information. In this way, the inhibition account of age-related differences extends to an impaired ability to suppress irrelevant speech in older people.

The findings of Experiment 2 confirm that age-related differences in performance become more pronounced in the presence of irrelevant speech if the ISI is relatively short. To our knowledge, this is the first study in which irrelevant speech and a short ISI were combined in order to increase task complexity. Previous research has shown that the performance of older individuals is not disproportionately compromised by a short ISI (Craik & Rabinowitz, 1985) and irrelevant speech alone (this study), but when these factors are combined, the performance of older adults is compromised more than is the performance of younger adults. In addition to larger age differences in intrusion errors in the short relative to the long ISI condition, this suggests that inhibitory processes in older adults are less efficient under time pressure. When extended to daily life, this suggests that older people need more time to memorize verbal information when they are in a noisy environment.

ACKNOWLEDGMENTS

Address correspondence to J. Jolles, Brain and Behavior Institute, Department of Psychiatry & Neurology, University of Maastricht, P.O. Box 616, 6200 MD Maastricht, the Netherlands. E-mail: j.jolles@np.unimaas.nl

REFERENCES
