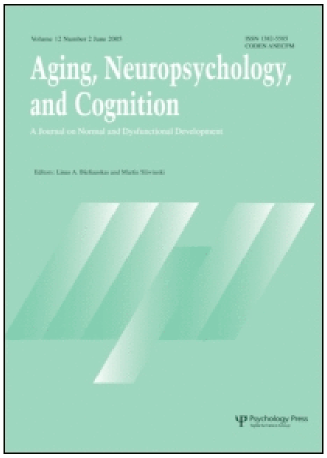


Aging, Neuropsychology, and Cognition

Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713657683

Effects of Noise on Identification and Serial Recall of Nonsense Syllables in Older and Younger Adults

To cite this Article: , 'Effects of Noise on Identification and Serial Recall of Nonsense Syllables in Older and Younger Adults', Aging, Neuropsychology, and Cognition, 14:2, 126 - 143
xxxx:journal To link to this article: DOI: 10.1080/13825580701217710
URL: http://dx.doi.org/10.1080/13825580701217710

Aging, Neuropsychology, and Cognition, 14: 126–143, 2007
http://www.psypress.com/anc
ISSN: 1382-5585/05 print; 1744-4128 online
DOI: 10.1080/13825580701217710

Psychology Press
Taylor & Francis Group

Effects of Noise on Identification and Serial Recall of Nonsense Syllables in Older and Younger Adults

AIMEE M. SURPRENANT
Memorial University of Newfoundland, St. John's, NL, Canada

ABSTRACT

The present experiment investigated the hypothesis that age-related declines in cognitive functioning are partly due to a decrease in peripheral sensory functioning. In particular, it was suggested that some of the decline in serial recall for verbal material might be due to even small amounts of degradation due to noise or hearing loss. Older and younger individuals identified and recalled nonsense syllables in order at a number of different speech-to-noise ratios. Performance on the identification task was significantly correlated with performance on a subsequent serial recall task. However, this was restricted to the case in which the stimuli were presented in a substantial amount of noise. These data show that even small changes in sensory processing can lead to real and measurable declines in cognitive functioning as measured by a serial recall task.

INTRODUCTION

It is well known that there is a decline in many types of memory performance as a function of age (see Zacks et al., 2000 for a recent review). Previous research has suggested that this decline is not due to any single cause. On the contrary, multiple factors seem to be needed in order to generate a comprehensive account of the effects of aging on memory. Some of the major variables that have been identified as factors contributing to the difficulties in cognitive processing experienced by older adults in general, and memory in particular, are reductions in attentional or working memory capacity (Baddeley, 1986; Craik, 1986), slowed speed of processing (Salthouse, 1996) and lack of inhibitory control (Hasher & Zacks, 1988; Hasher et al., 1999).

Address correspondence to: Aimee M. Surprenant, Psychology Department, Memorial University of Newfoundland, St. John's, NL, Canada A1B 3X9. E-mail: asurpren@mun.ca

In addition, recent reports have demonstrated strong relationships between basic sensory/perceptual capabilities and cognitive functioning. For example, Baltes and Lindenberger (1997), Lindenberger and Baltes (1994) reported that up to 70% of the variance in measures of intellectual ability for subjects ranging in age from 25 to 101 years could be accounted for by a composite score that included age, vision and hearing abilities. In a separate study, speed of processing effects on intelligence were almost entirely mediated by vision and hearing scores (Lindenberger & Baltes, 1994). The cognitive factors mentioned above could be re-interpreted in light of these results. For example, it is possible that at least some of the slowing in speed of processing is because basic input processes result in impoverished input that then takes more time to identify and interpret. In addition, difficulties in perceptual processing could take away resources that normally would be devoted to higher-level processing such as rehearsal or elaboration, resulting in reduced working memory capacity. Reduced inhibitory control could be an after-effect of reduced perceptual processing: the ability to focus on one stimulus while filtering out irrelevant information is reduced in the auditory system by the upward spread of masking found in hearing loss and in the visual system by loss of contrast information. More recent experiments and reviews have further supported the substantial relations between sensory and cognitive functioning (e.g., Scialfa, 2002; Schneider et al., 2002). This sort of direct effect of perceptual difficulties on cognitive processing has been called the *information-degradation* hypothesis (Schneider & Pichora-Fuller, 2000).

The reduced resources view gains at least partial support by the findings that impoverished input results in less automatic and more effortful processing of auditory (Alain et al., 2004) and visual (Atchley & Lesa Hoffman, 2004) stimuli. These and other investigations (Lindenberger et al., 2001) make the point that the deficit is probably not due purely to sensory acuity but to an interaction between the sensory and cognitive functioning.

However, given the correlational nature of the previous studies, the direction of causality cannot be conclusively determined. Lindenberger and Baltes (1994) (see also Lindenberger et al., 2001), for example, suggested that a third factor, widespread neural degeneration, might cause both perceptual and cognitive deterioration (the common cause hypothesis). Another logical possibility actually reverses the causality and suggests that cognitive declines could cause a depletion of resources at a higher level which takes away resources that would normally be devoted to the perceptual system (the cognitive load on perception hypothesis). In addition, the effects of perceptual deterioration could act gradually on cognitive processing and result in long-term changes in the cognitive system (the sensory deprivation hypothesis). Based on an extensive review of this literature with these possibilities in mind, Schneider and Pichora-Fuller (2000) concluded that there is likely to be a very complex relationship between perception and cognition because the two systems are very highly integrated and interdependent. They proposed an integrated system model of shared resources in which the flexible allocation of resources is a key ingredient. This essentially combines all of the above hypotheses and suggests that each one could play a role.

Effects of Perceptual Degradation on Memory

Most theories of cognition implicitly assume that if a stimulus is identified perfectly, then any difficulty in remembering that stimulus must be due to some higher-level cognitive deficit. In other words, it is assumed that encoding is independent of stimulus level, once some threshold is exceeded. However, we can show that when a person can identify stimuli perfectly but there is some sort of distortion of the signal or some background noise, memory is worse.

There have been a number of studies demonstrating an effect of perceptual degradation (due to noise or hearing loss) on memory. Rabbitt (1991) found that even mild peripheral sensory hearing loss resulted in a substantial reduction in the number of words recalled, compared to an age-matched control group with no hearing loss, even though identification performance (measured by shadowing the presented stimuli out loud) was essentially perfect for both groups. Similarly, Pichora-Fuller et al. (1995), using a variant of the speech-perception-in-noise test (Bilger et al., 1984), showed that older mildly-impaired subjects recalled fewer items than younger subjects even when levels of identification were equated. Pichora-Fuller et al. (1995) included a condition in which the sentences were read silently and showed no differences between the older and younger adults in their memory task. Thus, this effect was not due to differential memory abilities of the two groups.

Both Pichora-Fuller et al. (1995) and Rabbitt (1991) suggested that the added difficulty experienced by listeners with mild hearing loss depleted resources which might otherwise have been used to elaboratively encode and rehearse the materials. Thus, although the distortion of the signal had no overt effect on identification (Rabbitt, 1991), and identification performance was equated (Pichora-Fuller et al., 1995), there were still effects of hearing loss and aging on memory and comprehension (see also Rabbitt, 1990). In addition, Humes et al. (1993) (see also Luce et al., 1983) showed that identification and recall of synthetic speech was poorer than natural speech. Similar results have been reported when the input modality is visual (Salthouse et al., 1996; Schneider & Pichora-Fuller, 2000).

Murphy et al. (2000) looked at the detailed pattern of performance and found that they could "simulate" the effects of aging by adding noise to the to-be-remembered stimuli. They used a paired-associate paradigm in which old and young subjects were given lists of five pairs of words to learn. At test, they were given the first of those words back as a retrieval cue. Some of the word pairs were degraded by adding noise. Both noise and age groups showed detrimental effects of noise on the initial serial positions in this paradigm but the final positions were unaffected. The effects of noise were similar to the effects of aging. That is, their younger subjects showed the same pattern of results as the older subjects but only when noise was added to the stimuli. One explanation they gave of their data was that perceptual deficits associated with aging result in an impoverished memory trace, as if the stimuli had been presented in noise. Another possible explanation of their data is that in order to hear each stimulus in a noisy environment the listeners had to expend resources that are normally devoted to rehearsing the stimuli. Murphy et al. (2000) concluded that either or both explanations could account for their data. Murphy et al. (2000) did measure their subjects' auditory thresholds.

Surprenant (1999) asked participants to identify and then recall nonsense syllables under different levels of noise. Even though there was no effect of the noise on identification of the syllables there were significant decrements in serial recall performance. An identical pattern was obtained in a subsequent experiment in which the stimuli were presented with different levels of filtering to simulate different severities of high-frequency hearing losses. Both of the experiments showed that degradation of the stimulus by noise led to reductions in performance over all list positions, including the final position. Although listeners could identify the stimuli in the noise and simulated hearing loss conditions just as well as they did with no noise or distortion, these subjects nevertheless had to expend more effort to understand each utterance. This led to poorer recall over the entire list.

The experiments reported in Surprenant (1999) were not designed to study individual differences, but even though there were not many subjects, there were significant correlations between an individual's identification performance in noise and overall level of recall ($0.5<r$ values<0.6). It is reasonable to expect, then, that individual differences in identification ability may be able to predict overall levels of recall of words in noise, even when the words are identified at close to ceiling levels. If one person is expending more effort to understand each word than someone who is encoding the stimuli with no difficulty, this could result in poorer performance on a serial recall task. One might conclude that there is a deficit at a relatively high cognitive level that is, in fact, due to a deficit in efficient encoding.

Age Effects in Serial Recall

In immediate serial recall, participants are asked to repeat a sequence of stimuli in the order in which they were presented. When the same items are repeated on every trial, the task mainly requires memory for the order of a sequence. With young adults and auditory presentation performance on the first few (primacy effect) and last (recency effect) items in the list is quite good compared to the items in the middle of the list (Crowder, 1976). Even though a similar pattern of results is generally found when older adults are tested, overall recall is generally much lower (e.g., Maylor et al., 1999).

The current experiment was designed to examine the possible relation between identification performance and immediate serial recall. Immediate serial recall was chosen as a task because there is a large literature on serial order memory and it has been a basis for most of the models and theories of immediate or short-term memory. However, there is little known about the effects of initial perceptual encoding on serial recall. The approach used in the current experiment was to measure each individual's ability to identify nonsense syllables over a range of speech-to-noise ratios in order to construct individual identification functions. Noise levels were manipulated in order to obtain a range from near perfect to chance performance. Then, serial order memory for lists of those syllables was measured at three levels of noise. Because the main interest was on the effect that noise, by itself, would have on memory, nonsense syllables were chosen as stimuli. This was done in order to preclude the use of strategies such as previous knowledge or contextual clues that have been shown to ameliorate some of the effects of sensory-perceptual losses (Hutchinson, 1989; Nittrouer & Boothroyd, 1990; Wingfield, 2000).

Participants were also asked to answer some questions about their day-to-day hearing experiences. In addition, participants completed a standard measure of working memory capacity (operation span) and a phonological coding (rhyming) task. We included the operation span task as a measure of the attentional capacity of our participants. Although it was originally developed as a working memory task, current thinking is that it is more of a measure of attentional capabilities than a memory task (Bunting et al., 2004; Unsworth & Engle, 2005). The phonological coding task was included as a measure of the ability of the participants to translate orthographic information into an acoustic or phonological code. If there are differences between the older and younger adults in this ability, we might conclude that the older adults are less proficient at generating such a code, which, it is generally agreed, is the basis for serial recall (e.g., Conrad, 1964).

EXPERIMENT

Method

Participants

Seventy-five adults from the Purdue University community between the ages of 30 and 80 were tested over approximately two sessions of 1 h each in exchange for $20. An additional seven participants did not meet the hearing screening requirements and were excused. One more participant's (age 34) data was discarded because s/he performed at ceiling on the recall task (100% for all serial positions in all noise conditions). Twenty-three of the participants were between ages 30 and 39; 21 between 40 and 49; 10 between 50 and 59; and 20 were between 60 and 80. Fifty-four of the 75 participants were women; 21 were men. Seventy-one of the participants were right-handed, four were left-handed. Two of the left-handers were women; two were men. Most of the participants worked as professionals or as clerical staff at the university. Two were housewives and twenty were retired. None of the participants were currently taking any prescription drugs that have side effects that impair perceptual or cognitive functioning. All of the participants reported being in good health.

Materials and Procedures

On arrival at the lab for the first session participants were given a hearing screening (described below). Seven individuals failed to meet our criterion and were excused. The rest of the participants were then given the tasks/measures in the following order: Mini Mental Status Exam, rhyming task, operation span (OSPAN), identification of syllables in noise, and serial recall of syllables. The participants completed the screening measures and the rhyming and OSPAN tasks in the first session and the identification and recall tasks in the second.

Screening Procedures

Hearing Screening

Pure-tone audiometric thresholds were measured at 250, 500, 1000, 2000, and 4000 Hz. Seven participants were outside the range considered to be clinically normal up to 4 kHz (greater than 20 dB HL) and were excused from participation. The rest of the participants passed the screening.

Mini Mental Status Examination (MMSE)

The “Mini” Mental Status Exam (Folstein et al., 1975) is a quick way to evaluate cognitive function and is often used to screen for dementia or monitor its progression. The test consists of orienting questions including date and place, naming objects, counting backward, recall of short series and following written and verbal commands. Answers are graded and the total number of points possible is 30. Scores of 24 or above are considered normal. All participants in this study scored above 28.

Experimental Procedures

Rhyming Task

In the rhyming task participants were shown a set of four words that appeared all at once on a computer screen. The words had similar spellings, but one word did not rhyme with the others (e.g., drives, wives, gives, and knives). The stimuli were taken from Tehan and Lalor (2000). The subjects’ task was to identify the odd word (the word that did not rhyme with the others) from the set as quickly as possible and click on it using the computer mouse.

Each trial began by the participant clicking on a button labeled “Next Trial”. The words remained on the screen until a response was made. Response times and accuracy were recorded. There were 30 trials total. The location of the odd word in the actual experiment was randomized.

Operation Span (OSPAN)

This task was developed to investigate working memory capacity in a task that had minimal verbal requirements (Conway & Engle, 1995). Our version of this task was very similar to that of Unsworth et al. (2005). Participants were informed that we were interested in how accurately they could remember the order in which a series of words had been presented whilst solving simple math problems. First, a math problem was shown [e.g. (10/2)+4=9?] and participants were asked to read it out loud (e.g., “Is ten divided by 2 plus 4 equal to 9?”). They then clicked on a button (yes or no) to answer the question. A word then appeared for 2 s and the subjects were instructed to read the word aloud. Math problems and words alternated until the desired number of words (2, 3, 4, 5, or 6) had been presented. Then, response buttons became active and were labeled with the words in alphabetical order. The participants were asked to indicate the presentation order of the words by clicking on appropriately labeled buttons on the screen using the mouse. Subjects received three practice trials (not scored) with list length 2, followed by 15 scored trials, three lists at each length from 2 to 6. The order of list lengths was randomly determined for each participant.

Identification Task

The stimuli for the identification task were six consonant–vowel syllables (ba, da, ga, ka, pa, ta) recorded by a female talker and digitized at 44 kHz. The syllables were presented at 65 dB SPL and were mixed with broadband noise at various intensities to construct *S/N* ratios of −20, −15, −10, 0, +5, and +25. Listeners were seated in a single-walled listening booth equipped with an IBM-compatible computer monitor and keyboard. All stimuli were presented binaurally via TDH-39 headphones. The stimuli were generated from stored raw files by a TDT System II 16-bit D/A converter and were adjusted to the proper intensity via a TDT programmable attenuator.

Participants were allowed to listen to each stimulus twice. The name of the syllable was displayed on the computer screen while the stimulus was played. Participants were then given 180 identification trials; five trials for each of the six consonants at each of the six *S/N* ratios. Participants were allowed to take a break after every block of 30 trials. For each trial a syllable was presented over the headphones and participants were asked to identify it by pressing one of six keys on the computer keyboard overlaid with the names of the syllables. Feedback was given.

Serial Recall

The serial recall segment of the experiment always immediately followed the identification phase. Participants were given a list consisting of a random permutation of all of the six syllables that were presented in the identification phase. After the conclusion of each list participants were instructed to respond by recreating the list in strict serial order by pressing the keys on the keyboard that were overlaid with the syllable name. Participants were not allowed to go back and change any response and no feedback was given. Three noise levels were used in the memory phase: 0, +5, and +25 *S/N* ratio, and there were 25 lists at each noise level for a total of 75 trials. Noise level was blocked and participants were always given the +25 condition first, followed by the +5 and 0 conditions. This was to enable the subjects to practice the task under close to ideal circumstances before experiencing the more difficult conditions.

RESULTS

Basic Statistics

Rhyming Task

Average accuracy on the Rhyming task was over 96% correct. A Komolograv–Smirnov test for normality was significant (K–S $d = .26$, $p < .01$) indicating that the distribution differed significantly from a normal distribution. Because of this ceiling effect, the accuracy data were not analyzed further. Mean response time for the Rhyming test was 4.3 s (median = 4.2; standard deviation = 1.2 s). Komolograv–Smirnov test for normality was not significant (K–S $d = .10$; $p > .20$) thus the distribution did not differ significantly from a normal distribution.

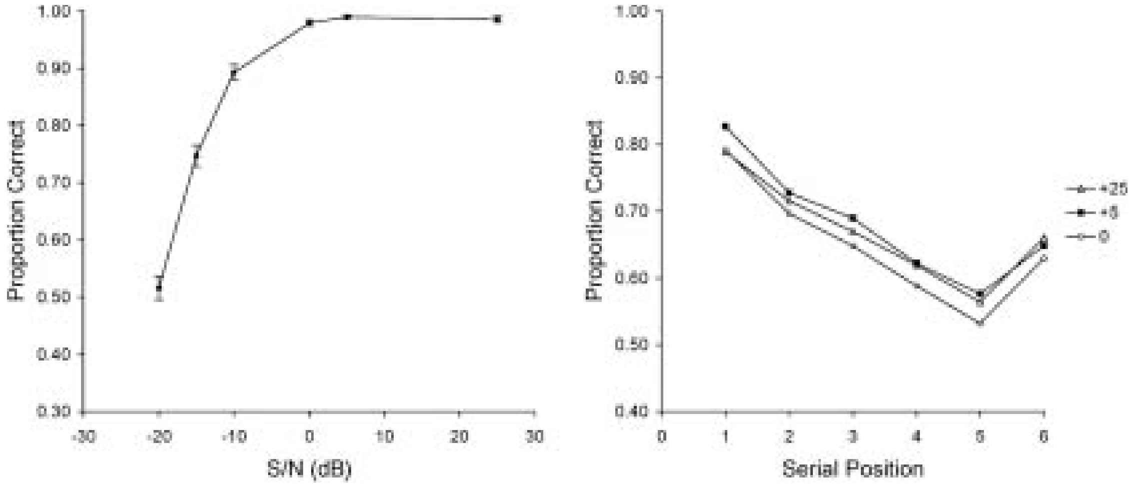
Operation Span

Operation span (OSPAN) is the sum of list lengths correctly recalled. If a participant correctly recalls all three words from a three-item list correctly, three points are added to the OSPAN total. Thus, the minimum is 0 and the maximum is 60. In this experiment, the mean OSPAN score was 33.59 (median = 34.00; *SD* = 12.56; range = 1–55). Komolograv–Smirnov test for normality was not significant (K–S $d = .09$; $p > .20$) thus the distribution does not differ from a normal distribution.

Identification Task

The left panel of Figure 1 shows identification functions averaged across all participants. There was a main effect of *S/N* ratio on identification of the syllables ($F(5,370) = 330.85$, $MSE = 2.68$, $p < .01$). *Post-hoc* analysis

FIGURE 1. Overall proportion correct identification averaged across participants as a function of *S/N* ratio in dB (left panel). Error bars are the standard error of the mean. Overall proportion correct averaged across participants as a function of serial position and *S/N* ratio (right panel).



(Fisher's LSD) of just the three levels of noise that were used in the memory task (0, 10, and 25 dB *S/N*; proportion correct of .98, .99, .98, respectively) showed no differences. The entire function closely resembles psychometric functions for identification of all kinds of materials across various signal-to-noise ratios.

The left panel of Figure 2 shows identification functions broken into three equal categories by age. It is evident that, at the 0 *S/N* ratio, all groups are performing the task equally. However, at the −10 *S/N* ratio level, there is clear separation between the groups.

Serial Recall

The right panel of Figure 1 shows serial recall performance averaged across all subjects. Overall memory performance was disrupted in the 0 dB *S/N* condition, replicating the results of Surprenant (1999). There was a significant main effect of noise [$F(2, 148) = 4.69$, $MSE = 0.02$, $p < .01$], a main effect of position [$F\ (5, 370) = 91.81$, $MSE = 0.01$, $p < .01$] but no interaction between the two [$F(10, 740 = 1.0$, ns]. This replicates the findings reported by Surprenant (1999). *Post-hoc* LSD tests show that the 0 dB *S/N* condition was different from the other noise conditions but that the 5 and 25 dB *S/N* conditions did not differ from one another. The right panel of Figure 2 shows serial recall performance (collapsed across *S/N* ratio) broken down into three equal categories by age. It is clear that there are substantial differences in recall among the groups at every serial position.

Overall identification and memory performance closely replicates the results of Surprenant (1999). However, the question we are most interested in is whether we can predict serial recall performance (as measured by serial recall) from performance on the identification task (as measured by the 70% threshold measure described above). In the following section correlational analyses are reported among the main experimental variables.

Individual Identification Functions

Psychometric functions were fit to each individual's identification data and a threshold was calculated at 70% correct. (This is an arbitrary point on the function: there were no substantial differences in the conclusions if a different threshold, such as 80% correct, was used.) Figure 2 shows example fits to the identification data for two subjects. The speech-to-noise ratio for 70% identification along the fitted function is marked by the arrows and 0 dB *S/N* circled. (The actual thresholds were obtained by using the formula that was used to generate the function.) Notice the difference in the functions. At 0 dB *S/N*, although both subjects were almost perfect in identifying the stimuli, Subject 38 was starting to have difficulty (see Figure 3). If even a little more noise were added, that individual would have failed at the

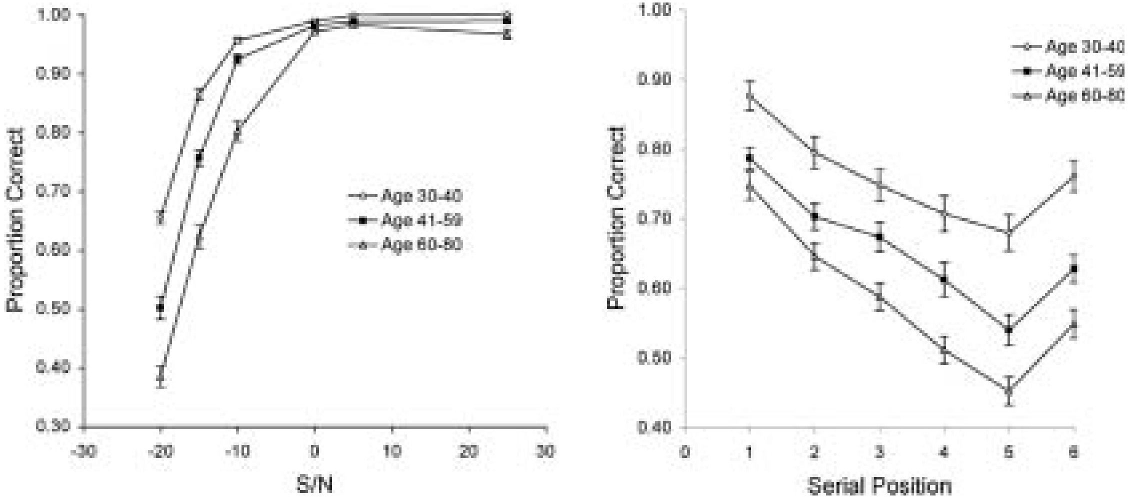
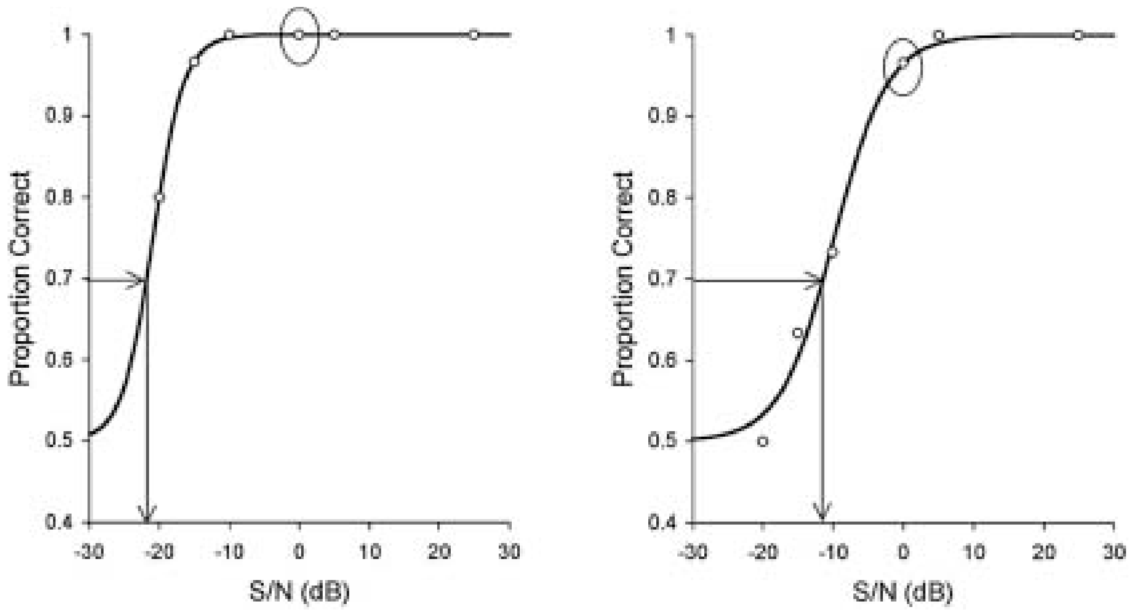


FIGURE 2. Overall proportion correct identification broken down by age group as a function of *S*/*N* ratio in dB (left panel). Error bars are the standard error of the mean. Overall proportion correct broken down by age group as a function of serial position (right panel).

FIGURE 3. Proportion correct identification for Subject 27 (left panel) and Subject 38 (right panel) as a function of *S/N* ratio in dB. The arrows indicate the 70% threshold. The circles indicate the 0 dB *S/N* ratio condition.



identification task. However, Subject 27 would have needed 10–20 dB more noise before she experienced any difficulty in identifying the stimuli. Even with equivalent identification performance at this point, it is clear that there are substantial differences in the ease with which the two subjects were identifying the stimuli. Overall, there was a considerable range of performance on this task with the best and the worst subjects separated by a speech-to-noise ratio of over 18 dB.

Correlational Analyses

The full correlation matrix is displayed in Table 1. For all analyses, an alpha level of 0.05 was adopted. For correlations with $N = 75$, r values greater than 0.23 are significant according to a two-tailed test.

Rhyme Task

Performance on the Rhyme test was correlated with recall in the +25, +5 but not 0 dB conditions ($r = -.26, -.23, -.19$, respectively) but not with age ($r = .13$) or any other variable. This task was included in order to provide a measure of phonological coding ability. Although it is accounting for some of the variance in the recall conditions (especially in quiet) it is not a huge factor. It is probable that phonological coding ability was not tapped in the recall task because the same syllables were repeated over and over. In addition, because the stimuli contrasted only in the initial consonant, the contribution of perceptual factors might have overwhelmed the phonological factors. The lack of a correlation between age and the rhyme task suggests that the participants did not differ in their ability to form abstract phonological representations. Thus we can rule out one possible explanation of the group-related differences.

Operation Span

Because OSPAN is a working memory measure, it was expected to correlate with age and memory performance. However, although there were reliable correlations between serial recall and OSPAN ($r = .31, .34, .31$ for

TABLE 1. Correlations among the Experimental Variables

	Age	OSPAN	Rhyme	+25 dB	+5 dB	0 dB	70% Thresh
Age	1.00						
Ospan	–0.08	1.00					
Rhyme	0.13	0.07	1.00				
+25 dB	**–0.42**	**0.31**	**–0.26**	1.00			
+5 dB	**–0.40**	**0.34**	**–0.23**	**0.84**	1.00		
0 dB	**–0.53**	**0.31**	–0.19	**0.76**	**0.81**	1.00	
70% Thresh	**0.59**	–0.10	0.16	**–0.39**	**–0.37**	**–0.52**	1.00

Note: Significant correlations ($p < .01$) are indicated in bold face.

+25, 5, 0 dB conditions, respectively) there were no significant correlations between OSPAN and any of the other measures, including age. Recent research using the operation span task has shown that it is much more closely linked with attentional capabilities than with memory, *per se*, or even intelligence (Bunting et al., 2004; Unsworth & Engle, 2005).

Identification

Identification performance at the +25, +5, and 0 dB *S*/*N* ratios was at ceiling and did not differ as a function of age. However, once the noise was loud enough, age differences started to emerge. This is not surprising given the many studies showing that older adults, even with normal hearing, very often have difficulty understanding speech in noisy environments (e.g., Gordon-Salant & Fitzgibbons, 1995; Versfeld, & Dreschler, 2002). The correlation between age and identification performance at the different *S*/*N* ratios bear this out (r = −.25, −.20, .−20, −.59, −.60, −.64 for +25, +5, 0, −10, −15, −20 dB conditions, respectively).

Age, Serial Recall, and Threshold

The main result of interest is the relationship among age, serial recall and the identification threshold measure. Seventy-percent identification threshold was significantly correlated with recall for syllables in all of the conditions but much more strongly in the 0 dB condition than in the other conditions (r = −.39, −.37, −.52 for +25, 5, 0 dB conditions, respectively). Recall performance was also significantly correlated with age (−.42, −.40, −.53 for +25, 5, 0 dB conditions, respectively), but was not so affected by the level of noise presented with the stimuli. Finally, age and 70% threshold were significantly correlated (r = .59).

Partial correlations with serial recall as the dependent variable showed that both threshold and age contributed significantly and about equally to recall in the 0 dB condition (β = −.31, −.34, respectively) but that age and not threshold was a significant contributor in the +5 and +25 dB conditions. Thus, it seems that perceptual identification becomes relevant only when the stimuli are difficult to perceive. Age, on the other hand, contributes to memory performance regardless of the difficulty in perceiving the stimuli.

GENERAL DISCUSSION

There are many factors that contribute to differences in memory performance in young and older adults. Factors such as reductions in attentional or working memory capacity (Baddeley, 1986; Craik, 1986), slowed speed of processing (Salthouse, 1996) and lack of inhibitory control (Hasher & Zacks, 1988; Hasher et al., 1999) all have been shown to contribute to this difference. The experiment reported here suggests that another factor, perceptual efficiency, should be added to the list of factors, particularly in conditions of degraded stimulus quality.

Even a small amount of noise can affect speech identification performance, particularly when the participants are elderly or have a mild hearing loss (Dubno et al., 1984). The individual functions generated from the identification phase show that even when identification performance is equivalent, it cannot be assumed that individuals are performing with the same perceptual efficiency. By measuring identification at a number of different levels, individual differences in how noise affects performance start to become evident. If processing resources are taxed by adding noise, even when identification is essentially perfect, higher-level cognitive processes like memory can be substantially affected. One way in which older adults can compensate for reduced perceptual sensitivity is by "borrowing" resources from higher level cognitive functions but this comes at the cost of reduced cognitive performance. Thus, careful consideration of peripheral sensory input must be considered as a factor in the measurement of cognitive abilities across the lifespan.

These data show that there is an effect of perceptual efficiency on higher level processes, particularly when processing is made very difficult. However, that effect may be limited to situations in which top-down information is not available and/or the task critically depends on proper identification of the stimuli. For example, Lindenberger et al. (2001) showed that simulated sensory deficits did not immediately result in decreased performance on their battery of tests. Their tasks, however, were standard cognitive battery tasks and included a great deal of redundant information that could be used by the participants to compensate for the simulated deficits.

In line with this, Lindenberger et al. (2001) did find an effect of noise in a listening span task in which the participants needed to rely heavily on initial sensory encoding in order to perform the task. The other tasks in their battery have been specifically modified to be easily encoded by individuals with vision or hearing loss and thus are presented bi-modally or in large font and high contrast. In the present study, nonsense syllables were used as stimuli in a deliberate attempt to prohibit the use of previously-existing knowledge or context that might be used to compensate for degraded input. Thus, in tasks in which initial encoding is critical, the present results argue for a careful consideration of sensory acuity. In these cases it is not sufficient to assume that performance is equal because both groups are performing at ceiling levels. Only when conditions are difficult enough do differences start to appear.

Researchers investigating cognitive aging have not, on the whole, considered basic sensory acuity as a factor in their experiments. In a recent review of 288 published studies on cognitive aging, Schneider and Pichora-Fuller (2000) found that less than 25% of the investigators even measured visual or auditory acuity. The other studies either ignored the issue or obtained self-reports of auditory or visual difficulties. Thus, in the majority of the research to date, there is little objective information on the sensory capabilities of the subjects. The data reported here make it clear that basic sensory acuity may play a substantial role in serial recall and that difficulty in encoding may only show its effects at later cognitive stages, such as memory (Pichora-Fuller & Schneider, 2000; Rabbitt, 1968).

These insights are critical when interpreting age-related performance on higher-level cognitive tasks. If the older adults are expending more effort encoding each stimulus, they may show deficits that are interpreted as being due to cognitive decline but are, in fact, due to reductions in sensory processing. Although only one-third of adults over the age of 70 have clinically-significant hearing losses, almost 100% have some mild losses, compared to the typical 20-year-old, particularly at the higher frequencies (Goodhill, 1979). These small deficits can have cascading effects that only appear at higher cognitive levels. Thus, both researchers and clinicians need to be sensitive to the possibility that sensory acuity is a contributing factor in performance, particularly if the test relies heavily on initial encoding efficiency.

The major aim of this project was to focus attention on peripheral sensory decrements that are routinely present in older adults to help explain some of the age-related declines in cognitive functioning. Because the declines in these areas are gradual, they are often ignored until significant decrements are observed. These data show that even small changes in sensory processing lead to real and measurable declines in cognitive functioning as measured by a serial recall task.

ACKNOWLEDGEMENTS

This material is based upon work supported, in part, by the National Science Foundation under Grant No. 0074721 and by a Gerontology Program Pilot Grant awarded by the Gerontology Program at Purdue University. Portions of this manuscript were written while the author was a Visiting Fellow at the Memory Research Unit, Department of Psychology, City University, London, UK.

Original manuscript received February 26, 2005
Revised manuscript accepted September 29, 2005

REFERENCES

Alain, C., McDonald, K. L., Ostroff, J. M., & Schneider, B. (2004). Aging: a switch from automatic to controlled processing of sounds? *Psychology and Aging, 19,* 125–133.

Atchley, P., & Hoffman, L. (2004). Aging and visual masking: sensory and attentional factors. *Psychology and Aging, 19,* 57–67.

Baddeley, A. D. (1986). *Working memory*. Oxford: Oxford University Press.

Baltes, P. B., & Lindenberger, U. (1997). Emergence of a powerful connection between sensory and cognitive functions across the adult life span: A new window to the study of cognitive aging? *Psychology and Aging, 12,* 12–21.

Bilger, R. C., Nuetzel, M. J., Rabinowitz, W. M., & Rzeczkowski, C. (1984). Standardization of a test of speech perception in noise. *Journal of Speech and Hearing Research, 27,* 32–48.

Bunting, M. F., Conway, A. R. A., & Heitz, R. P. (2004). Individual differences in the fan effect and working memory capacity. *Journal of Memory and Language, 51,* 604–622.

Conrad, R. (1964). Acoustic confusions in immediate memory. *British Journal of Psychology, 55,* 75–84.

Conway, A. R. A., & Engle, R. W. (1996). Individual differences in working memory capacity: More evidence for a general capacity theory. *Memory, 4,* 577–590.

Cox, R. M., & Gilmore, C. (1990). Development of the profile for hearing aid performance (PHAP). *Journal of Speech and Hearing Research, 33,* 343–357.

Craik, F. I. M. (1986). A functional account of age differences in memory. In F. Klix & H. Hagendorf (Eds), *Human memory and cognitive capabilities.* Amsterdam: Elsevier.

Dubno, J. R., Dirks, D. D., & Morgan, D. E. (1984). Effects of age and mild hearing loss on speech recognition in noise. *Journal of the Acoustical Society of America, 76,* 87–96.

Folstein, M. F., Folstein, S. E., McHugh, P. R. (1975). Mini-mental state: A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research, 12,* 189–198.

Goodhill, V. (Ed.) (1979). *Ear diseases, deafness, and dizziness.* New York: Harper-Collins.

Gordon-Salant, S., & Fitzgibbons, P. J. (1995). Recognition of multiply degraded speech by young and elderly listeners. *Journal of Speech & Hearing Research, 38,* 1150–1156.

Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. In G. Bower, (Ed.), *The psychology of learning and motivation* (Vol. 22). New York: Academic Press.

Hasher, L., Zacks, R. T., & May, C. P. (1999). Inhibitory control, circadian arousal, and age. In D. Gopher & A. Koriat (Eds), *Attention and performance XVII. Cognitive regulation of performance: Interaction of theory and application.* Cambridge, MA: MIT Press.

Humes, L. E., Nelson, K. J., Pisoni, D. B., & Lively, S. E. (1993). Effects of age on serial recall of natural and synthetic speech. *Journal of Speech and Hearing Research, 36,* 634–639.

Hutchinson, K. M. (1989). Influence of sentence context on speech perception in young and older adults. *Journals of Gerontology, 44,* P36–P44.

Lindenberger, U., & Baltes, P. B. (1994). Sensory functioning and intelligence in old age: A strong connection. *Psychology and Aging, 9,* 339–355.

Lindenberger, U., Scherer, H., & Baltes, P. B. (2001). The strong connection between sensory and cognitive performance in old age: Not due to sensory acuity reductions operating during cognitive assessment. *Psychology and Aging, 16,* 196–205.

Luce, P. A., Feustel, T. C., & Pisoni, D. B. (1983). Capacity demands in short-term memory for synthetic and natural speech. *Human Factors, 25,* 17–32.

Murphy, D. R., Craik, F. I. M., Li, K. Z. H., & Schneider, B. A. (2000). Comparing the effects of aging and background noise on short-term memory performance. *Psychology and Aging, 15,* 323–334.

Nittrouer, S., & Boothroyd, A. (1990). Context effects in phoneme and word recognition by young children and older adults. *Journal of the Acoustical Society of America, 87,* 2705–2715.

Pichora-Fuller, M. K., Schneider, B. A., & Daneman, M. (1995). How young and old adults listen to and remember speech in noise. *Journal of the Acoustical Society of America, 97,* 593–608.

Rabbitt, P. M. A. (1990). Applied cognitive gerontology: Some problems, methodologies and data. *Applied Cognitive Psychology, 4,* 225–246.

Rabbitt, P. M. A. (1991). Mild hearing loss can cause apparent memory failures which increase with age and reduce with IQ. *Acta Otolaryngology Supplement, 476,* 167–176.

Salthouse, T. A. (1996). The processing speed theory of adult age differences in cognition. *Psychological Review, 103,* 403–428.

Salthouse, T. A., Hancock, H. E., Meinz, E. J., & Hambrick, D. Z. (1996). Interrelations of age, visual acuity, and cognitive functioning. *Journal of Gerontology: Psychological Sciences, 51B,* P317–P330.

Schneider, B. A., & Pichora-Fuller, M. K. (2000). Implications of perceptual deterioration for cognitive aging research. In F. I. M. Craik and T. A. Salthouse (Eds), *The handbook of aging and cognition* (2nd ed.). Mahwah, NJ: LEA.

Schneider, B. A., Daneman, M., & Pichora-Fuller, M. K. (2002). Listening in aging adults: From discourse comprehension to psychoacoustics. *Canadian Journal of Experimental Psychology, 56,* 139–152.

Scialfa, C. T. (2002). The role of sensory factors in cognitive aging research. *Canadian Journal of Experimental Psychology, 56,* 153–163.

Surprenant, A. M. (1999). Effects of noise on memory. *International Journal of Psychology, 34*, 328–333.

Surprenant, A. M., & Neath, I. (1996). The relation between discriminability and memory for vowels, consonants, and silent-center syllables. *Memory & Cognition, 24,* 356–366.

Tehan, G., & Lalor, D. M. (2000). Individual differences in memory span: The contribution of rehearsal, access to lexical memory, and output speed. *Quarterly Journal of Experimental Psychology, 53A,* 1012–1038.

Unsworth, N., & Engle, R. W. (2005). Working memory capacity and fluid abilities: Examining the correlation between Operation Span and Raven. *Intelligence, 33,* 67–81.

Unsworth, N., Heitz, R. P., Schrock, J. C., & Engle, R. W. (2005). An automated version of the operation span task. *Behavior Research Methods, Instruments, & Computers, 37,* 498–505.

Versfeld, N. J., & Dreschler, W. A. (2002). The relationship between the intelligibility of time-compressed speech and speech in noise in young and elderly listeners. *Journal of the Acoustical Society of America, 111,* 401–408.

Wingfield, A. (2000). Speech perception and the comprehension of spoken language in adult aging. In: D. C. Park and N. Schwarz (Eds), *Cognitive aging: A primer* (pp. 175–195). New York, NY: Psychology Press.

Zacks, R. T., Hasher, L., & Li, K. Z. H. (2000). Human memory. In F. I. M. Craik and T. A. Salthouse (Eds), *The handbook of aging and cognition* (2nd ed.). Mahwah, NJ: LEA.