The Quarterly Journal of Experimental Psychology Section A
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713683590

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Online Publication Date: 01 January 2005

To cite this Article McCoy, Sandra L., Tun, Patricia A., Cox, Clarke L., Colangelo, Marianne, Stewart, Raj A. and Wingfield, Arthur(2005)'Hearing loss and perceptual effort: Downstream effects on older adults' memory for speech',The Quarterly Journal of Experimental Psychology Section A,58:1,22 — 33

To link to this Article: DOI: 10.1080/02724980443000151

URL: http://dx.doi.org/10.1080/02724980443000151

THE QUARTERLY JOURNAL OF EXPERIMENTAL PSYCHOLOGY
2005, 58A (1), 22–33

Psychology Press
Taylor & Francis Group

Hearing loss and perceptual effort: Downstream effects on older adults' memory for speech

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A group of older adults with good hearing and a group with mild-to-moderate hearing loss were tested for recall of the final three words heard in a running memory task. Near perfect recall of the final words of the three-word sets by both good- and poor-hearing participants allowed the inference that all three words had been correctly identified. Nevertheless, the poor-hearing group recalled significantly fewer of the nonfinal words than did the better hearing group. This was true even though both groups were matched for age, education, and verbal ability. Results were taken as support for an *effortfulness hypothesis*: the notion that the extra effort that a hearing-impaired listener must expend to achieve perceptual success comes at the cost of processing resources that might otherwise be available for encoding the speech content in memory.

The cognitive declines associated with normal ageing are well known and well described in the cognitive literature. These declines include reductions in the capacity of working memory (Salthouse, 1991; Wingfield, Stine, Lahar, & Aberdeen, 1988), attentional difficulties in inhibiting irrelevant stimuli (Barr & Giambra, 1990; Hasher & Zacks, 1988; Stoltzfus, Hasher, & Zacks, 1996), and slowing in many perceptual and cognitive operations (Cerella, 1994; Fisher & Glaser, 1996; Salthouse, 1996) All of these factors may contribute to the common complaint among older adults of increasing difficulty with memory for recently experienced events (Kausler, 1994).

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This research was supported by NIH Grant AG19714 from the National Institute on Aging. We also gratefully acknowledge support from the W.M. Keck Foundation. The authors would like to thank Patrick Rabbitt, John Towse, and two anonymous reviewers for their helpful comments.

http://www.tandf.co.uk/journals/pp/02724987.html DOI:10.1080/02724980443000151

Although there is wide individual variability, the biological changes that accompany the ageing process also include an increased incidence of hearing loss, especially in the higher frequency ranges that are important for the accurate perception of speech (Morrell, Gordon-Salant, Pearson, Brant, & Fozard, 1996). It is clearly the case that the older adult's ability to recall what has been heard, whether from a spoken conversation with family or friends, or medication instructions from a health care provider, will depend significantly on the individual's ability to hear the full message. Speech in everyday environments is also often heard in noisy backgrounds, a factor known to further challenge the older auditory and cognitive systems (Gordon-Salant, 1987; Tun, 1998; Tun, O'Kane, & Wingfield, 2002; Tun & Wingfield, 1999; Working Group on Speech Understanding and Aging, 1988).

There is an additional concern, however, that arises even when the loudness and clarity of the speaker allow the listener with a mild-to-moderate hearing loss to correctly identify the speech being heard. This relates to what one may call an *effortfulness hypothesis*: the notion that the extra effort that a hearing-impaired listener must expend to achieve this perceptual success may come at the cost of processing resources that might otherwise be available for encoding the speech content in memory.[1]

The potential negative consequence of effortfulness in perceptual processing on subsequent memory performance was demonstrated in a classic set of experiments by Rabbitt (1968). Rabbitt (Exp. 1) showed poorer recall for strings of spoken digits by normal-hearing adults when the digits were noise masked, even when the level of masking still allowed accurate recognition of the to-be-recalled digits. As a further illustration, Rabbitt gave listeners 8-digit lists, temporally grouped into two 4-digit lists by a 2-s pause after the first 4 digits. He found that the first half of the list, whether presented in quiet or masked by noise, was less well recalled when the second half had been heard in noise than when it had been heard in quiet (Rabbitt, 1968, Exp. 2). As Rabbitt later summarized the implication of these findings, "the increased effort necessary to discriminate speech correctly through low levels of random noise may draw on information processing capacity which subjects can otherwise employ to rehearse the words they have to remember" (Rabbitt, 1991, p. 169).

Rabbitt (1991) expanded this principle by showing an analogous effect for older adults with mild hearing loss. In this case he showed that word lists were better recalled by individuals with good hearing than by those with mild hearing loss, even when both groups showed the ability to correctly repeat words presented at the same intensity level. As in the case of the noise-masking studies with normally hearing adults, Rabbitt argued that persons with impaired hearing may have to invest more processing resources to identify spoken words than do individuals with better hearing. This would have the effect of reducing available processing resources that might otherwise be deployed for maintenance or elaborative rehearsal to encode the words in memory for later recall. This general principle was reinforced by Murphy, Craik,

[1]We use the terms "resources" and "resource capacity" in Kahneman's (1973) original sense, to refer to a limited pool of attentional resources that must be allocated among tasks. In Kahneman's formulation, processing resources for a particular task will be diminished if access to the same resources is required for performance of multiple tasks that must be performed concurrently or in close sequence: in this case, perceptual processing of the spoken words and their encoding in memory. The more difficult or resource demanding a particular task, the fewer resources will be available for use elsewhere in the system. As such, Kahneman's notion of resource capacity is used in the same sense as Baddeley's (1996, 1998) notion of a limited-capacity central executive in working memory.

Li, and Schneider (2000) who used noise masking to simulate a hearing loss in young and older adults with good hearing. (See also discussions by Pichora-Fuller, Schneider, & Daneman, 1995; and Tun & Wingfield, 1999.)

However compelling this argument, there is a simpler account of why older adults with some degree of hearing loss might display poorer recall for spoken material than do older adults with good hearing. One might refer to this as a sensory account: the proposition that recall deficits of poor-hearing older adults are a direct consequence of an auditory system in which sensory registration is so degraded as to prevent the identification of lexical items necessary for encoding in memory and effective rehearsal. This strong version of a sensory account of recall deficits, however, must be modified in view of the substantial body of research that has demonstrated that linguistic context can moderate the effects of hearing loss. For example, when final words of spoken sentences are masked with noise, hearing loss produces smaller effects on word recognition in highly predictable sentence contexts than in low predictability contexts (Dubno, Ahlstrom, & Horwitz, 2000; Gordon-Salant & Fitzgibbons, 1997; see also Pichora-Fuller et al., 1995). Therefore, a purely sensory account must be modified to include not simply overall differences between good-hearing and poor-hearing listeners, but also larger recall differences for low-predictability material.

Although one should not underestimate how failures in initial perception can impact recall, in this experiment we ask whether not merely the degradation of sensory input but also the extra effort required for successful perception by older adults with hearing loss might even affect immediate recall of short, subspan messages. We chose for this study older adults with mild-to-moderate hearing loss because of the prevalence of this level of impairment and the fact that this group typically does not use hearing aids on a regular basis (National Academy on an Aging Society, 1999).

The test paradigm we chose was a running memory span, in which the participant was asked to listen carefully to a list of recorded words that would be stopped at any moment. When the list was stopped the task was to recall only the last three words heard. We chose a set size of three words because this is generally within the immediate memory span of healthy older adults in both simple (Kausler, 1994; Wingfield, Stine, Lahar, & Aberdeen, 1988) and running memory (Wingfield, Lahar, & Stine, 1989) span tests for spoken words.

Our first step in this test was to demonstrate that participants could recall the final word of the three-word set in order to ensure that both participants with hearing loss and participants with good hearing could correctly identify the words. For this purpose we relied on the well-known finding that word-list recall reflects a recency effect, in which the last items of a list, and especially the final item, show a very high level of recall. This is true for both short and long lists (Murdock, 1962), and it holds for older adults as well as for young adults (Kahana, Howard, Zaromb, & Wingfield, 2002; Kausler, 1994).

Our logic was as follows: If the final word in a set can be reported correctly by a listener, we can assume that he or she was just as likely to have correctly identified all three words in the set, which were all spoken by the same speaker at the same intensity level. That is, the ability to correctly report the final word would allow the inference that the listener had successfully identified, or achieved lexical access, for all three words. Thus, poorer recall of the first two words by a group with hearing loss, relative to a better hearing group, would be due not simply to an inability to correctly identify the words, as predicted by a purely sensory account. Instead, we suggest that such a differential failure of recall of the earlier words in the set would be due to the increased burden on processing resources experienced by the hearing loss group, who must expend greater effort to achieve perceptual success, or redintegration of a stimulus word from a weak trace (Neath, 2000; Newbigging, 1961). This drain on resources could deprive the participant of the necessary resources for adequate encoding of the materials in memory and thus result in poorer downstream recall. This is the essence of the effortfulness hypothesis.

To complete the full picture of everyday memory, albeit in microcosm, we wished also to examine recall performance when the to-be-recalled words were supported by contextual constraints. One would expect to see such facilitation, as it is well known that older adults, like young adults, benefit from linguistic context in the recognition of words heard under poor listening conditions. Indeed, it is a general principle of perception that the higher the probability of a stimulus, as determined, for example, by contextual constraints, the less sensory information is required for correct recognition (Morton, 1969). This includes listeners with good hearing recognizing words from just their acoustic onsets (Perry & Wingfield, 1994; Wingfield, Aberdeen, & Stine, 1991), listeners with good hearing recognizing words heard in background noise (Pichora-Fuller et al., 1995), and young and older adults with a mild-to-moderate hearing loss (Gordon-Salant & Fitzgibbons, 1997).

All of the studies cited above presented target words in the context of a grammatically coherent sentence. In such cases there are several sources of contextual constraint, including constraints on grammatical form class (the word “a” signals that the next word will be a count noun or an adjective) and semantic meaning (the sentence context “the train pulled into the” increases the likelihood of particular words such as “station,” “tunnel,” “siding,” or “village”).

In the interests of testing the generality of context effects as a balance against hearing loss in word recognition, we wished to determine whether one could facilitate recognition using linguistic constraints lacking ordinary syntactic and semantic structure. To this end we chose as stimuli so-called *statistical approximations* to English as a means of capturing the predictive quality of language based just on short-range associations (Miller & Selfridge, 1950; Moray & Taylor, 1960). Miller and Selfridge originally constructed these approximations by giving a participant several words of a sentence and asking him or her to guess what the next word might be. This sequence was then shown to another person who was asked to guess the next word, and so on, until a text of a desired length had been developed. The degree of contextual constraint is defined by the order of approximation: 1st order is text in which each word choice is based on one word of context (“realizing most so the together home and for were wanted”), 2nd order is text in which each word is based on two words of prior context (“sun was nice dormitory is I like chocolate cake”), 3rd order is text in which each word is based on three words of prior context (“family was large dark animal came roaring down the middle of my friends love books”), and so forth. These examples, taken from Miller and Selfridge (1950), show that as the orders of approximation are increased the resultant word sequences increase their resemblance to meaningful English, but only in regard to their short-range associations.

Based on prior studies (e.g., Murphy et al., 2000; Rabbitt, 1968, 1991) we had two predictions. The first was that older adults with age-related hearing loss would show poorer recall for the first two words of three-word recall sets than would age-matched older adults with good hearing, even when accurate recall of the final word of the three-word set implies that words not recalled had been correctly identified, albeit with greater effort on the part of the group with poorer hearing.

Our second prediction, based also on an effortfulness notion, was that the effect of hearing loss on recall would be reduced or eliminated with higher order approximations to English that increase the transitional probabilities of the stimulus words in the to-be-recalled word sets. This prediction is based on the assumption that this contextual support would facilitate perception (e.g., Morton, 1979), thus leaving more resources available for encoding the words in memory. By contrast, one would expect to see stronger effects of hearing loss on recall for word sets that do not provide contextual support. Of special note, we wished to determine whether one could demonstrate these effects not with relatively demanding memory tasks, or comprehension of complex discourse, but with simple recall of just three spoken words.

Method

Participants

The participants were 24 healthy, community-dwelling volunteers, 16 women and 8 men, ranging in age from 66 to 81 years ($M = 72.9$ years, $SD = 4.1$). All were native English speakers with good levels of education and verbal ability. All reported themselves to be in good health, with no history of stroke, Parkinson's disease, or other neuropathology that would compromise their ability to perform the research task.

Participants were tested audiometrically (air and bone conduction) to ensure that hearing loss was sensorineural in nature. Individuals with conductive or eighth nerve (retrocochlear) disorders were not used. Following otoscopic examination by an audiologist trained in otoscopy, tympanometry was conducted on all participants to document middle ear integrity and to help rule out conductive hearing loss. Distortion product otoacoustic emissions (DPOAEs) were obtained to help confirm cochlear hearing loss and to reject participants with possible auditory neuropathy (Starr, Picton, Sininger, Hood, & Berlin, 1996). Word recognition scores were also obtained, and subjects with results poorer than expected for their sensorineural hearing loss were excluded.

The participants were divided into two groups of 12 based on their puretone averages (PTAs) averaged across 1,000, 2,000, and 4,000 Hz, a frequency range known to be a good predictor of perceptual performance for speech (Humes, 1996). One group of 12 participants, referred to as the *better hearing* group, had PTAs of less than or equal to 25 dB in the better ear, which was the right ear for 7 of the participants. The PTAs of this group ranged in the better ear from 8.3 dB to 25.0 dB ($M = 21.4$ dB). The remaining 12 participants, referred to as the *hearing loss* group, had PTAs greater than 25 dB in the better ear, which was the right ear for 6 of the participants. Their PTAs ranged from 28.3 dB to 51.7 dB ($M = 35.7$ dB). Table 1 shows mean pure tone thresholds and standard deviations in the better (test) ear for the two participant groups across the range from 250 to 6000 Hz.

Although the two groups differed in hearing acuity they were equivalent in age [better hearing, $M = 72.5$ years, $SD = 4.7$; hearing loss, $M = 73.4$, $SD = 3.7$; $t(22) = 0.53$, *ns*], education [better hearing, $M = 16.5$ years, $SD = 1.8$; hearing loss, $M = 16.6$ years, $SD = 1.8$; $t(22) = 0.91$, *ns*], and verbal ability as assessed by the Shipley Vocabulary Test [Zachary, 1986; better hearing, $M = 16.5$, $SD = 2.2$; hearing loss, $M = 16.8$, $SD = 2.4$; $t(22) = 0.71$, *ns*].

Stimulus materials

The stimuli consisted of 16 strings, each 15 words in length, taken from Miller and Selfridge (1950). These represented four general degrees of contextual constraint, each comprising four lists. In decreasing order of contextual constraint these were (a) two lists each of 7th and 9th order of approximation to English, (b) two lists each of 4th and 5th order of approximation to English, (c) two lists each of 2nd

TABLE 1
Mean thresholds (in dB HL) and standard deviations for the better hearing and hearing loss participants

	Group			
	Better hearing		*Hearing loss*	
Frequency (Hz)	*M*	*SD*	*M*	*SD*
250	15.8	4.7	20.0	8.0
500	16.3	3.8	24.6	6.6
1,000	13.8	4.3	22.9	7.5
2,000	18.8	7.1	34.2	8.2
3,000	24.6	8.9	46.7	11.3
4,000	31.7	11.3	50.0	13.7
6,000	45.8	12.9	56.3	11.1

Note: Data shown for better ear.

and 3rd order of approximation to English, and (d) two lists each of 0 and 1st order of approximation to English. For the 1st-order approximations each word was based on one word of prior context. The zero-order stimuli were random sequences of words that approximated the number of syllables in the other orders (e.g., "better write catch native evening bit position wish small proper grass").

In our analysis it is our intent to contrast higher order approximations with the 0- and 1st-order approximations. This is so because these two lowest level approximations were either not constrained by previous text (0 order) or constrained by only one word of previous text (1st order). For all of the orders of approximation from 2nd order and higher, each of the words to be recalled was constrained by at least two prior words. That is, even the first word in a three-word memory set had a minimum of two prior words of constraining context, as did the second and third words to be remembered. Thus, it is only 0- and 1st-order approximations that are not constrained to this degree.

All of the stimulus sequences were recorded by a female speaker of American English at a rate of one word per second to create a series of sound files using SoundEdit software (Macromedia, Inc., San Francisco, CA) for the Macintosh computer (Apple, Cupertino, CA). The lists were equated for sound intensity using a Larson-Davis 800B sound level meter (Larson Davis, Inc., Provo, UT).

Procedure

Each participant heard all 16 word-lists with order of presentation of word lists randomized between participants. Instructions were to listen carefully to each word list as it was presented. As soon as the list was finished, participants were prompted to recall the last three words by the appearance of three large asterisks on a computer screen directly in front of them. Participants were told to be ready for recall at any moment as the lists might be stopped at any time. To maintain this level of attention, the lists heard by each participant were randomly stopped for recall after 5, 7, 8, 10, 12, 13, 14, or 15 words. Regardless of list length, however, instructions were to recall just the last three words heard.

All testing was conducted in a sound-attenuated testing room, with the lists presented monaurally to the participant's better ear using Eartone 3A (E-A-R Auditory Systems, Aero Company, Indianapolis, IN) insert earphones. Stimuli were presented at a level of 75 dB HL to the better ear via a Maico MA 42 audiometer (Maico Diagnostics, Eden Prairie, MN) using Psyscope presentation software (Cohen, MacWhinney, Flatt, & Provost, 1993). Prior to the main experiment, participants completed a brief practice session in which they heard four word-lists of varying lengths and contextual constraint to familiarize them with the experimental instructions and report procedures. None of these practice lists was used in the main experiment.

Results

The recall test performance is summarized in Figure 1 for the better hearing (left panel) and hearing loss (right panel) groups. The vertical bars in each panel show the average percentage of correct recall for the first two words of the three-word sets for the various orders of approximation. For ease of presentation we have clustered the higher constraint approximations into three groups (from left to right: combined 7th and 9th order, combined 4th and 5th order, combined 2nd and 3rd order). The single vertical bars on the right in each panel show the mean percentage of correct recall for the first two words of the low contextual constraint group (combined 0 and 1st order).

As indicated previously, an important check for the analysis of word recall was to ensure that the last word of each of the three-word sets was recalled correctly. This high level of accuracy would allow the presumption that the first two words of the set had also been heard. This criterion was amply met: Across all approximation levels, the mean accuracy in reporting the final words of the three-word recall sets was 99.5% correct for the better hearing group and 98.2% for the hearing loss group. As a very conservative check on presumed perceptual registration of these to-be-remembered words, we show in Figure 1 accuracy scores only for those cases where the final words of the three-word sets were reported correctly. All analyses to be described below were also conducted on just these cases.

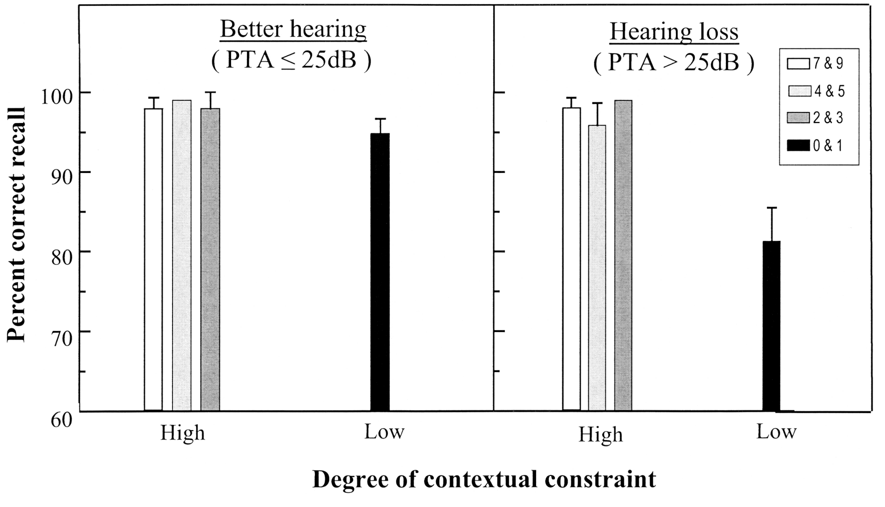

Figure 1. Percentage of correct recall for the first two words of three-word recall sets for word sequences with high contextual constraints (2nd-through 9th-order approximations to English) and low contextual constraints (0- and 1st-order approximations). Data are shown for better hearing participants (pure tone average, PTA, less than or equal to 25 dB HL; left panel) and for participants with hearing loss (PTA greater than 25 dB HL; right panel). Error bars represent one standard error. Error bars are absent where they were too small to plot.

Inspection of Figure 1 shows that, for both groups, recall levels for the first two words of each three-word recall set are at ceiling or near ceiling for the three high contextual constraint groups (2nd through 9th orders of approximation), but that the recall level is lower when the level of constraint is low (0 and 1st orders of approximations). Importantly, this latter effect is differentially greater for the hearing loss group than for the better hearing group. These trends were confirmed by a series of analyses of variance (ANOVAs) conducted on these data.

We first conducted a 4 (approximation level: 7th & 9th, 4th & 5th, 2nd & 3rd, 0 & 1st) × 2 (hearing: better hearing, hearing loss) mixed design omnibus ANOVA, with approximation level as a within-participants factor and hearing group as a between-participants factor. The appearance in Figure 1 that order of approximation had a significant effect on recall was confirmed by a significant main effect of approximation level, $F(3, 66) = 9.34$, $MSE = 0.063$, $p < .001$. There was also a significant main effect of hearing group, $F(1, 22) = 7.76$, $MSE = 0.005$, $p < .025$. The observation that the effect of hearing loss depended on the order of approximation of the stimulus set was confirmed by a significant Hearing Group × Approximation Level interaction, $F(3, 66) = 4.20$, $MSE = 0.063$, $p < .01$.

To verify the impression in Figure 1 that the source of this interaction was in the effect of hearing on the low constraint sets (0 and 1st order) we first conducted a subsidiary two-way ANOVA on just the higher order approximation stimuli (the three approximation groups ranging from 2nd through 9th order), excluding the combined 0- and 1st-order data. As we can see, with this small recall ensemble, presented with these degrees of contextual constraint, performance was virtually at ceiling. As would thus be expected, this analysis failed to show significant main effects of either approximation level, $F(2, 44) < 1$, $MSE = 0.004$, or hearing group, $F(1, 22) < 1$, $MSE = 0.003$, nor was there a significant Approximation Level × Hearing Group interaction, $F(2, 44) < 1$, $MSE = 0.004$. By contrast, when we conducted a one-way ANOVA comparing the two hearing groups on just the low constraint sets (0 and 1st order) there was a significant difference between the hearing groups, $F(1, 22) = 8.65$, $MSE = 0.001$, $p < .01$.

As part of this analysis, however, we required a further test of our assumption that the greater number of errors made by the poor hearing group in the low context conditions was due not to a failure of perceptual identification of the words, but to a detrimental effect on memory encoding resulting from increased effort in perceptual processing of the stimulus words. To the extent that this is correct, one would expect to see no effect of participants' hearing acuity on recall of the final word of a three-word set, but one would expect to see a significant difference between the two hearing groups on the prior two words.

Planned-comparison testing conducted on the three serial positions of the recall sets confirmed this expectation: There was no significant difference between the good and poor hearing groups on recall accuracy for the final word of the three-word sets (good hearing, $M = 100\%$ correct; poor hearing, $M = 97.9\%$; $SD = 0.07$), on either a two- or a one-tailed significance test, $t(11) = 1.00$, *ns.* In contrast, hearing acuity had a significant effect on recall of the second-to-last word of the three-word set (good hearing, $M = 100\%$; poor hearing, $M = 87.5\%$; $SD = 0.17$), $t(11) = 2.57$, $p < .05$, and on recall of the first word of the three-word set (good hearing, $M = 89.6\%$; $SD = 0.13$; poor hearing, $M = 72.9\%$; $SD = 0.25$), $t(11) = 2.06$, $p < .05$. (Inspection of these accuracy rates offers a suggestion of a graded effect of hearing acuity, with the difference between the good and poor hearing groups increasing as one proceeds backward in serial position. An ANOVA conducted on these data, however, failed to show a significant Hearing Group × Serial Position effect due, most probably, to the generally high levels of recall for both groups.)

Discussion

As Rabbitt (1968) originally noted, we are often forced to listen to speech over a poor telephone line (or today over cell phones with a weak signal) or speech partially masked by environmental noise. In the case of many older adults, these environmental contributors to less-than-clear speech are further compounded by a hearing loss, especially in the higher frequency ranges that affect consonant recognition (Morrell et al., 1996).

Such losses in signal clarity, whether a consequence of ambient noise, hearing loss, or both, need not necessarily be sufficient to produce errors in recognition. The question we raise, however, is whether the perceptual and inferential efforts required for the successful recognition of a degraded signal may take a toll on processing resources that might otherwise be used for downstream operations. Such potentially vulnerable downstream operations would include the ability to encode the materials in memory through rehearsal or to comprehend text meaning at a propositional level, often in the face of rapid speech with complex syntax. Such effects could lead not only to the reduced memory performance seen here but also, potentially, to the perhaps erroneous impression of reduced cognitive function in the listener. Indeed, one could entertain an analogous concern in the case of vision, where even modest sensory impairment might have significant secondary effects on downstream processes such as memory (Dickinson & Rabbitt, 1991).

The present results have shown that the added perceptual effort required for successful recognition by participants with a mild-to-moderate hearing loss was sufficient to affect memory performance when recall of just three words was required. This illustrates that the perceptual effort required to successfully identify words may affect recall in a situation far less demanding than the memory tasks used in the prior studies of participants with hearing loss (Rabbitt, 1991) or the effects of noise on recall by participants with good hearing (Murphy et al., 2000; Rabbitt, 1968).

To isolate the source of this effect it was necessary that we showed that the recall failures for the low-constraint words by the hearing loss group were not due to a failure to identify the words, albeit with some effort. Because both groups correctly reported the final words of the three-word sets, we can infer that they also identified the prefinal words, which were recorded by the same speaker and at the same intensity. We thus conclude that the larger number of recall failures for the prefinal words by the hearing loss group was not due to a failure of recognition, but to the necessary allocation of greater processing resources to achieve this successful identification. This point was emphasized in our analysis, which used only those cases where the final word was reported correctly.

These data go beyond prior studies that have used meaningful sentences to supply contextual support for word recognition for degraded words (e.g., Perry & Wingfield, 1994; Pichora-Fuller et al., 1995; Wingfield et al., 1991) or with young and older adults with hearing loss (Gordon-Salant & Fitzgibbons, 1997). The current work shows that such constraints operate even with statistical approximations to English that mimic the predictive quality of natural language but without conveying semantic coherence (Miller & Selfridge, 1950; Moray & Taylor, 1960). Indeed, so long as each of the words to be recalled was constrained by at least two prior words (i.e., 2nd-order approximations and higher) hearing acuity had no effect on recall. As indicated earlier, the reason this is so lies in the nature of statistical approximations to English and our use of three-word memory sets. That is, with 2nd-order approximations every word in the three-word memory set is always constrained by at least two previous words. Thus, it is only 0- and 1st-order approximations that are not constrained to this degree.

The constraints offered by the higher orders of approximation may have operated to facilitate the recognition of the target words either by increasing their likelihood (Morton, 1969, 1979) or by decreasing the number of potential lexical possibilities (Marslen-Wilson, 1990) as the words were being heard. They may also have aided in retrospective recognition of words whose identity had originally been unclear (Grosjean, 1985; Wingfield, Alexander, & Cavigelli, 1994). Our presumption is that any or all of these effects might reduce the perceptual burden on the listener's processing resources. This would, in turn, leave more resources available for encoding the words in memory, resulting in more successful recall.

It should be recognized that the higher order approximations may have also affected performance by listeners using the transitional probabilities between the words to aid in reconstructive operations during the act of recall itself (Potter & Lombardi, 1990). None of these influences, however, would operate for the lower order approximations, and it was here that hearing acuity showed its effect. For older adults with hearing loss, the extra effort necessary to successfully recognize the words had a significant effect on memory for what had been heard.

In the case of everyday speech comprehension, and memory for what has been heard, the task takes on far more complexity than the simple recall task used here. Successful comprehension of everyday discourse must rely not only on lexical identification of the individual words, but also on the determination of the syntactic relations among the words and the development of a full coherence structure for what has been heard (e.g., Kintsch, 1988). In this more challenging world of comprehension and recall of rapid and sometimes complex speech, our results, and that of others (Murphy et al., 2000; Pichora-Fuller et al., 1995; Rabbitt, 1968, 1991), suggest a need on the part of the professional community to be sensitive to the possibility raised here: that the extra perceptual effort expended on the initial stages of speech recognition by listeners with even mild hearing loss may cause measurable failures in the downstream operations of comprehension and memory for what has been heard.

In this latter regard it should be noted that in this study we examined only people with hearing loss less than 50 dB. The nature of these data would lead us to presume that individuals with hearing loss greater than 50 dB would need to expend an even greater degree of perceptual effort to effect successful comprehension. It is the case that many older adults, as well as the general public, can be highly sensitive to even the smallest sign of cognitive decline (Erber, Prager, Williams, & Caiola, 1996). The present data support the argument that downstream effects of perceptual effort due to hearing loss might lead one to overestimate the degree of cognitive decline in an older listener. Alternatively, when cognitive decline is present, a performance decline might be further exacerbated by the combination of hearing loss and the burden on resources necessary to achieve perceptual success.

REFERENCES

Baddeley, A. D. (1996). The concept of working memory. In S. Gathercole (Ed.), *Models of short-term memory* (pp. 1–28). Hove, UK: Psychology Press.

Baddeley, A. D. (1998). The central executive: A concept and some misconceptions. *Journal of the International Neuropsychological Society*, *4*, 523–526.

Barr, R. A., & Giambra, L. M. (1990). Age-related decrement in auditory selective attention. *Psychology and Aging*, *3*, 597–599.

Cerella, J. (1994). Generalized slowing and Brinley plots. *Journal of Gerontology: Psychological Sciences*, *49*, 65–71.

Cohen, J. D., MacWhinney, B., Flatt, M., & Provost, J. (1993). Psyscope: An interactive system for designing and controlling experiments in the psychology laboratory using Macintosh computers. *Behavior Research Methods, Instruments, and Computers*, *25*, 257–271.

Dickinson, C. M., & Rabbitt, P. M. A. (1991). Simulated visual impairment: Effects on text comprehension and reading speed. *Clinical Vision Sciences*, *6*, 301–308.

Dubno, J. R., Ahlstrom, J. B., & Horwitz, A. R. (2000). Use of context by young and aged adults with normal hearing. *Journal of the Acoustical Society of America*, *107*(1), 538–546.

Erber, J. T., Prager, I. G., Williams, M., & Caiola, M. A. (1996). Age and forgetfulness: Confidence in ability and attributions for memory failures. *Psychology and Aging*, *11*, 310–315.

Fisher, D. L., & Glaser, R. A. (1996). Molar and latent models of cognitive slowing: Implications for aging, dementia, depression, development, and intelligence. *Psychonomic Bulletin and Review*, *3*, 458–480.

Gordon-Salant, S. (1987). Age-related differences in speech recognition performance as a function of test format and paradigm. *Ear and Hearing*, *8*, 270–276.

Gordon-Salant, S., & Fitzgibbons, P. J. (1997). Selected cognitive factors and speech recognition performance among young and elderly listeners. *Journal of Speech, Language, and Hearing Research*, *40*, 423–431.

Grosjean, F. (1985). The recognition of words after their acoustic offset: Evidence and implications. *Perception and Psychophysics*, *38*, 299–310.

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

Humes, L. E. (1996). Speech understanding in the elderly. *Journal of the American Academy of Audiology*, *7*, 161–167.

Kahana, M. J., Howard, M., Zaromb, F., & Wingfield, A. (2002). Age dissociates recency and lag recency effects in free recall. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *28*, 530–540.

Kahneman, D. (1973). *Attention and effort*. Englewood Cliffs, NJ: Prentice-Hall.

Kausler, D. M. (1994). *Learning and memory in normal aging.* San Diego, CA: Academic Press.

Kintsch, W. (1988). The role of knowledge in discourse comprehension: A construction-integration model. *Psychological Review*, *95*, 163–182.

Marslen-Wilson, W. D. (1990). Activation, competition, and frequency in lexical access. In G. T. M. Altmann (Ed.), *Cognitive models of speech processing* (pp. 148–172). Cambridge, MA: MIT Press.

Miller, G. A., & Selfridge, J. A. (1950). Verbal context and the recall of meaningful material. *American Journal of Psychology*, *63*, 176–185.

Moray, N., & Taylor, A. (1960). Statistical approximations to English. *Language and Speech*, *3*, 7–10.

Morrell, C. H., Gordon-Salant, S., Pearson, J. D., Brant, L. J., & Fozard, J. L. (1996). Age- and gender-specific reference ranges for hearing level and longitudinal changes in hearing level. *Journal of the Acoustical Society of America*, *100*, 1949–1967.

Morton, J. (1969). Interaction of information in word recognition. *Psychological Review*, *76*, 165–178.

Morton, J. (1979). Facilitation in word recognition: Experiments causing change in the logogen model. In P. A. Kolers, M. E. Wrolstad, & H. Bouma (Eds.), *Processing visual language*. New York: Plenum Press.

Murdock, B. B. (1962). The serial position effect in free recall. *Journal of Experimental Psychology*, *64*, 482–488.

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.

National Academy on an Aging Society. (1999, December). Hearing loss: A growing problem that affects quality of life. *National Academy on an Aging Society, Number 2*.

Neath, I. (2000). Modeling the effects of irrelevant speech on memory. *Psychonomic Bulletin and Review*, *7*, 403–423.

Newbigging, P. L. (1961). The perceptual redintegration of frequent and infrequent words. *Canadian Journal of Psychology*, *15*, 123–131.

Perry, A. R., & Wingfield, A. (1994). Contextual encoding by young and elderly adults as revealed by cued and free recall. *Aging and Cognition*, *1*, 120–139.

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*, 593–607.

Potter, M. C., & Lombardi, L. (1990). Regeneration in the short-term recall of sentences. *Journal of Memory and Language*, *29*, 633–654.

Rabbitt, P. M. A. (1968). Channel capacity, intelligibility and immediate memory. *Quarterly Journal of Experimental Psychology*, *20*, 241–248.

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

Salthouse, T. A. (1991). *Theoretical perspectives on cognitive aging*. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

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

Starr, A., Picton, T., Sininger, Y., Hood, L., & Berlin, C. (1996). Auditory neuropathy. *Brain*, *199*, 741–753.

Stoltzfus, E. R., Hasher, L., & Zacks, R. T. (1996). Working memory and aging: Current status of the inhibitory view. In J. R. Richardson (Ed.), *Working memory and cognition* (pp. 66–88). New York: Oxford University Press.

Tun, P. A. (1998). Fast noisy speech: Age differences in processing rapid speech with background noise. *Psychology and Aging*, *13*, 424–434.

Tun, P. A., O'Kane, G. O., & Wingfield, A. (2002). Distraction by competing speech in young and older adult listeners. *Psychology and Aging*, *17*, 453–467.

Tun, P. A., & Wingfield, A. (1999). One voice too many: Adult age differences in language processing with different types of distracting sounds. *Journal of Gerontology: Psychological Sciences*, *54B*, P317–P327.

Wingfield, A., Aberdeen, J. S., & Stine, E. A. L. (1991). Word onset gating and linguistic context in spoken word recognition by young and elderly adults. *Journal of Gerontology: Psychological Sciences*, *46*, P127–P129.

Wingfield, A., Alexander, A. H., & Cavigelli, S. (1994). Does memory constrain utilization of top-down information in spoken word recognition? Evidence from normal aging. *Language and Speech*, *37*, 221–235.

Wingfield, A., Lahar, C. J., & Stine, E. A. L. (1989). Age and decision strategies in running memory for speech: Effects of prosody and linguistic structure. *Journal of Gerontology: Psychological Sciences*, *44*, P106–P113.

Wingfield, A., Stine, E. A. L., Lahar, C. J., & Aberdeen, J. S. (1988). Does the capacity of working memory change with age? *Experimental Aging Research*, *14*, 103–107.

Working Group on Speech Understanding and Aging. (1988). Speech understanding in aging. *Journal of the Acoustical Society of America*, *83*, 859–895.

Zachary, R. (1986). *Shipley Institute of Living Scale, Revised manual*. Los Angeles: Western Psychological Services.

PrEview proof published online 7 July 2004