Aging and Speech Perception: Beyond Hearing Threshold and Cognitive Ability

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Running Head: Aging and Speech Perception

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Abstract

Background. Older adults manifest difficulties in speech perception, especially when speech is accompanied by noise or when speech is rapid. Several explanations have been suggested to account for age-related changes in speech perception, such as changes in hearing sensitivity or a more general decline in cognitive functioning. The purpose of the present study was to directly examine the relative contribution of hearing sensitivity and perceptual and cognitive factors in the understanding of age-related differences in speech perception under difficult conditions.

Method. Eighty nine healthy participants, with normal hearing thresholds, age 21 to 82 years, were tested for speech perception under four conditions: quiet, speech noise, white noise, and time-compressed speech at 60% compression rate. Since all participants had age-normal hearing, absolute thresholds were tested for click trains, 1kHz 15msec duration pure tone, 1kHz 50msec duration pure tone, and 1.8kHz 15msec duration pure tone, which are relatively short and discriminative for hearing ability. Cognitive ability was examined using WAIS-III matrices and digit span.

Results. When words were presented against a quiet background or against white noise speech perception was not significantly affected by aging, although in the latter case, increased thresholds predicted poorer speech perception. However, when words were presented against a background of speech noise or when speech was time-compressed at a 60% rate, age significantly predicted a decline in speech perception, even after controlling for hearing thresholds and cognitive functioning.

Conclusions. Hearing threshold for short sounds is the major factor predicting speech perception in background noise, across age, due to changes in hearing sensitivity or in
temporal resolution. For adult and aging population with preserved cognitive ability, cognitive functioning does not predict decline in speech perception.

*Key Words: Aging, Speech Perception, Cognitive ability, Hearing thresholds*
Introduction

Many older individuals, even if they do not suffer from extensive hearing loss, report difficulties in understanding speech especially under less favorable conditions, such as when speech is accompanied by noise or when speech is rapid. Some surveys [e.g., 1] have reported that over 30% of elderly individuals find it difficult to understand conversations in everyday listening situations. A number of studies have reported that older individuals were poorer than younger adults in word recognition, when speech was accompanied by several types of noise, e.g., white noise, speech noise, and speech babble [2-4], or when speech was compressed [e.g., 5,6].

Because of the well-documented age-related general decline in a variety of physiological, behavioral and cognitive functions, there are potentially several possible sources for the reported difficulties in speech perception. Among the well-documented age-related auditory changes is that of hearing sensitivity. As individuals age there is a progressive decrease in hearing sensitivity to pure tones, especially in the high frequency range. Presbycusis affects one of every three individuals under the age of 60. By age 80, nearly one half of all individuals suffer from presbycusis [7].

The hearing-sensitivity theory argues that presbycusis and other age-related changes in hearing are the main causes for the difficulties in speech perception reported by older individuals [6,8-12]. However, a number of studies have shown this explanation to be insufficient. Elderly individuals tended to have more difficulties in speech perception than was predicted by the hearing sensitivity theory even when their absolute hearing thresholds were matched to that of younger individuals [13-15].

The apparent presence of difficulties by the elderly in comprehending speech even when their thresholds are equated to younger individuals has led to an alternative explanation
of the age-related decline in speech perception that posits age-related changes in cognitive processes may also be an important factor in accounting for difficulties in speech perception [e.g., 16-18]. A number of studies have reported that difficulties in speech perception in young populations suffering from hearing difficulties can, in part, be attributed to cognitive factors [19,20]. Humes [21] reported that cognitive factors were the second major factor after hearing thresholds that accounted for the variance in speech perception scores in a population of elderly individuals outfitted with hearing aids.

Several researchers have suggested that poorer speech perception by older adults could be explained by a reduction in processing speed or "cognitive slowing" [5,6,22,23]. Other researchers have focused on difficulties in executive functioning associated with aging (including memory) and have suggested that a deficit in at least one of the executive control components (working memory, attention, and goal maintenance) could contribute to a reduction of the overall cognitive functioning in aging, and consequently lead to difficulties in successfully performing complex tasks, including speech perception [24-30].

If changes in hearing sensitivity and decline in certain cognitive functions are exclusively responsible for the reported decline in speech perception under difficult conditions by the elderly, then this would mean that were these variables to be controlled, age as an independent variable, would not predict any decline in speech perception. However, if age predicts difficulties in speech perception even when hearing sensitivity and cognitive functioning are controlled, this would imply that some additional variables associated with age are also involved in the age-related difficulties in comprehending speech.

Very few of the earlier studies have systematically examined the contributions of changes in hearing sensitivity, cognitive functioning or auditory temporal resolution and aging as separate predictor variables of speech perception performance in individuals, whose hearing thresholds are within the norms for their age groups and who do not require hearing
aid corrections. As a first attempt to clarify the contributions of the putative variables noted above as predictors of the age-associated decline in speech perception, we examined the separate contributions of hearing thresholds, cognitive function and aging on speech perception. Therefore, the major purpose of the present study was to test the hypothesis that speech perception declines as a function of age even after controlling for hearing thresholds and cognitive functioning. Since all the participants in the study had normal hearing relative to their age, we did not use the classical audiometric thresholds in this study, but hearing thresholds for shorter sounds (such as click trains, 15 and 50 msec pure tones) in order to have a discriminative measure with higher resolution of hearing sensitivity. We tested speech perception in a healthy sample of adults, ranging in age from 21-82, who were screened to exclude any individuals with hearing loss beyond the norm for his or her age group, or who evinced any cognitive deterioration.
Method

Participants

Eighty nine participants were included in the study, 46 (52%) females and 43 (48%) males, aged 21 to 82 (30 participants age 21-40, 30 participants aged 41-60, and 29 participants aged 61-82). Participants' age and sex were distributed equally. No correlation was found between age and years of education \( r = -.108, p > .05 \). All participants were screened for normal hearing thresholds meeting the criteria of Lebo and Reddell [31], and had interaural threshold differences less than 10 dB. All participants were native Hebrew speakers, had more than 12 years of education, and reported being healthy and independent in their functioning, with no history of diseases related to the central nervous system. Participants whose age was over 60 years also performed the Mini Mental State Examination (MMSE) [32]. All scores were 29-30 reflecting a high level of mental ability.

Tasks and stimuli

Absolute threshold was measured for short duration stimuli in an attempt to create a distinctive measure with higher resolution of hearing sensitivity in age-normal hearing population. In order to measure than participants' cognitive ability, participants performed two cognitive tasks that measures short-term working memory, and non-verbal general intelligence (i.e., matrices and digit span). Speech perception was tested four conditions that were designed to reflect different speech perception environments

Absolute threshold. Absolute thresholds were measured for click train, 1kHz pure tone 15msec duration, 1kHz pure tone 50msec duration, and 1.8kHz pure tone 15msec duration using a 2-forced-choice adaptive paradigm with a two-down-one-up methodology [33]. Three blocks of stimuli were presented to each subject. The first block of stimuli was considered practice. Thresholds were computed from the averaged thresholds of the last two blocks.
Thresholds were calculated as the mean of the last eight out of 10 reversals in the two-down-one-up paradigm.

*Cognitive ability.* Cognitive ability was measured using the Wechsler Adult Intelligence Test (WAIS-III) [34].

*Speech perception.* Speech perception was tested using four tasks: speech perception in quiet, speech noise, white noise, and time-compressed speech at 60% compression rates. In the quiet condition, words were presented with no background noise. In the speech noise condition, words were accompanied by background broadband noise composed of steady-state frequencies within the range of 0.5-2kHz (band-passed noise), while in the white noise condition words were accompanied by wide band white noise. The words in these conditions were presented at a rate of 120 wpm. Speech- and white noise were recorded using the Diagnostic Audiometer DA64 and were presented at a signal to noise ratio = 0dB. In the 60% time-compressed speech condition, words were compressed to be 60% of their original length, and were presented with no background noise at a rate of about 200 wpm with the same three seconds of silent interval between them. The compression was carried out using the WSOLA (Waveform Similarity Overlap and Add) algorithm [35]. This algorithm produces high quality time-scale modification of speech signals with no changes to other characteristics of the auditory stimuli, such as pitch. For all of the speech conditions, the silent gap between words was 2.5 seconds.

The words used in the speech perception tasks were taken from the HAB (Hebrew AB) test, which is the Hebrew version [36] of the AB words test [37]. The tasks were composed of 12 lists of ten one syllable Consonant-Vowel-Consonant meaningful words. The lists were phonemically balanced such that each list contains all of the consonants, and the vowels appear twice. The speech noise and white noise conditions were composed of four
lists each. The speech in quiet and the speech presented at 60% compression rate were composed of two lists each.

Apparatus

Speech perception tasks were presented using digital compact disk player with SONY’s Digital Reference MDR-CD770 earphones. Screening for hearing sensitivity was done using Danplex DA64 or Maico Hearing Instruments Ltd MA32 audiometers.

Procedure

The experiment was carried out in two sessions of two and a half hours each. The various tasks were performed in random order and were split between the sessions, except for the absolute threshold test which was always performed during the first test session. The first session included the screening procedure, during which participants were informed of the nature of the testing procedure and signed an informed consent. Participants then filled out a personal questionnaire, underwent audiometer testing and the performed the MMSE. All participants were paid an amount in NIS equivalent to $50 for participating in the study.

Results

Age and hearing sensitivity

Hearing sensitivity, as measured by the absolute threshold task, for the click train, and the 15-msec duration 1 kHz and 1.8 kHz tones declined significantly with age (Table 1). However, the threshold of the 50- msec duration 1 kHz tone did not change significantly with age. Based on these results, hearing sensitivity for the click trains, 1kHz, 15-msec duration,
and the 1.8 kHz 15-msec duration tones were statistically controlled for in the subsequent analyses that tested the relationships between age and speech perception.

**Age and cognitive ability**

Cognitive ability, as measured by the digit span test and matrices was not found to correlate significantly with age (Pearson's $r = -0.12$, $p > .05$; Pearson's $r = -0.08$, $p > .05$, for digit span and matrices, respectively). These results indicate that for the population sample in this study, there was no significant age-related decline in these cognitive abilities.

**Age and speech perception**

Speech perception accuracy (percent correct) is plotted as a function of age in Figure 1 for each of the speech conditions separately: 1) speech in quiet; 2) speech with white noise background; 3) speech with speech noise background; and 4) time-compressed speech. Note that the Pearson correlation between age and speech perception is not significant when speech is presented either in quiet ($r = -.07$, $p > .05$) or with white noise background ($r = -.14$, $p > .05$), but is significant when speech is presented with speech noise background ($r = .51$, $p < .0001$), and when speech is time-compressed ($r = .23$, $p = .03$).

In order to test whether age predicts speech perception after controlling for hearing sensitivity and cognitive ability, a series of four hierarchical linear regressions were applied to predict speech perception in quiet, in white noise, in speech noise, and time-compressed speech at 60% compression rate. In each regression analysis, three variables of hearing sensitivity, namely the absolute threshold for the click train, and the 15-msec duration 1 kHz and 1.8 kHz tones, were entered in Step 1, digit span and matrices scores were entered in Step 2, and age was entered in Step 3. Tables 2-5 present the results of these regression analyses. As can be seen in Tables 2-5, age did not predict speech perception in quiet and in white noise.
beyond hearing sensitivity and cognitive ability. However, age significantly predicted the decline in speech perception and explained a large part of the variance when words were presented in speech noise, and made a moderate contribution in predicting the decline in perceiving time-compressed speech at a 60% compression rate. These results indicate that speech perception significantly declines with age even after controlling for hearing sensitivity and cognitive ability when speech was time-compressed and when speech was presented with a speech noise background.

Next, we tested the possibility that perhaps age was a significant predictor of the decline in speech perception only for conditions that are generally more difficult. Table 6 presents accuracy levels of speech perception for the four speech conditions. A repeated-measures ANOVA conducted on accuracy levels by speech condition (speech in quiet, speech in white noise, speech in speech noise, speech at 60% compression rate) revealed a significant effect of speech condition on accuracy, $F(3, 86) = 271.03, p < .001$. Bonferroni's post-hoc analyses indicated that all four speech conditions significantly differed in difficulty. Speech perception was the most difficult when words were presented in a white noise background and was the easiest one when words were presented in quiet. Therefore, task difficulty cannot be the explanation for the age-related decline in speech perception when speech is time-compressed or when speech is presented against a background noise.
Discussion

The major findings of the present study relate to the decline in speech perception associated with aging. A number of recent studies have shown that older adults are poorer than younger adults in word recognition, when speech was accompanied by several types of noise, e.g., white noise, speech noise, and speech babble [2-4], or when speech was time- compressed [5,6]. In the present study, we examined changes in speech perception in a population of healthy individuals, aged 21-82, screened for: 1) hearing thresholds within the normal range for their age; 2) intact cognitive functioning, as measured by the Mini Mental State Examination [32]; and 3) with no differences in level of education.

We found that both speech perception in speech noise and speech perception in white noise conditions were associated with hearing sensitivity. The common feature for these conditions is that words were presented against background noise. The results suggest that when noise accompanies speech, hearing sensitivity plays a role in the perception, as compared to when speech is not accompanied with noise, even when it is rapid (such as in time compressed speech). In contrast to the condition of speech presented against white noise background, when words were presented against a background of speech noise, speech perception was also significantly predicted by aging after controlling for hearing thresholds and cognitive functioning (as measured by performance on the digit span and matrices tasks). Similarly, when speech was time-compressed at a 60% rate, age significantly predicted a decline in speech perception, after controlling for hearing thresholds and cognitive functioning. Both speech perception in speech noise and in time-compression represent difficult conditions for speech perception which might explain the association with age. Along this line, we would have expected such an association also with the speech perception in white noise which was not observed in the current study. A small variability in this
measure, due to floor effect, might explain the lack of relationship between age and speech perception in white noise.

A number of factors have led researchers to suggest that age-related difficulties in speech perception reflect more general age-related changes in basic perceptual and cognitive functions. First of all, speech perception and production are very likely dependent upon the normal functioning of a number of sensory and perceptual as well as cognitive mechanisms [e.g., 19]. Perceiving spoken language is cognitively and perceptually complex. The listener must perform a perceptual analysis of the speech sounds, identify each word, resolve the syntactic structure of what is being heard, and integrate the newly arriving information with a memory trace of what has already been heard [38,39]. All this must be accomplished at speech rates which, even in ordinary conversation, average between 150 and 250 words per minute [40-41]. Second, there is a growing literature that documents an age-related general decline in a variety of physiological, behavioral and cognitive functions, including those very closely related to speech perception, e.g., speed of cognitive processing [24,26,42]. Consequently, two of the more popular candidates as possible sources for the age-related difficulties in speech perception have been: 1) changes in hearing sensitivity; and 2) decline in cognitive functioning.

A number of researchers have suggested that presbycusis and other age related changes in hearing sensitivity are the main causes for the difficulties in speech perception in older individuals [6,8-12,43]. This approach implies that one should be able to predict decline in speech perception by changes in hearing sensitivity, unrelated to their ages. In fact, the extent of hearing loss has been shown to be a significant predictor variable for speech recognition performance in individuals with hearing impairment, even when they wear their hearing aids. For example, Humes [21] tested 171 new and experienced hearing aid wearers (aged 60-87) and reported that the decline in speech recognition was predicted both by the
extent of hearing loss and by cognitive function. Furthermore, Humes reported that the “(hearing loss) factor alone accounted for 53.2% of the variance in speech recognition factor scores and was the single largest contributing factor among predictor variables”. When Humes analyzed a sub-group of his participants with “milder amounts of hearing loss”, the amount of variance accounted for by the hearing loss factor was 14.8%. Nevertheless, this was also approximately half of the variance accounted for by all of the factors (33.9%) for that sub-group of listeners.

Humes’ findings that hearing thresholds were less of a factor in predicting speech perception in the participants who were less impaired lead to the suggestion that speech recognition for older individuals with very mild hearing loss, may either not be significantly predicted by hearing thresholds, or if significantly predicted, the variance accounted for may be much less than for individuals with hearing loss levels that require correction by hearing aids [21]. Our findings are consistent with this conclusion. We examined speech perception in individuals whose thresholds were within the normal range for their age, and who were not hearing aid wearers. In order to measure hearing sensitivity in higher resolution and to enable variance in hearing sensitivity in spite having all the participants screened for age-normal hearing thresholds, we used hearing sensitivity for short sounds. We found that when words were presented against a background of white noise or speech noise, speech perception was significantly predicted by hearing thresholds. The amount of variance accounted for, however, was 10.1% when speech was presented in white noise and 19.5% when speech was presented in speech noise (see Table 3 and 4, step 1 results). These findings, thus, tend to support the conclusion that although hearing thresholds may be a major factor in accounting for the explained variance in speech perception scores, this factor accounts for less of the variance in participants whose thresholds are within the normal range for their age, as compared to the more impaired participants in the study reported by Humes [21].
Although changes in hearing thresholds account for a large amount of the variance of speech perception under certain difficult conditions, other variables have also been implicated. A number of researchers have suggested that reduced hearing sensitivity was not a sufficient explanation for the decline in speech perception in older individuals [13-15]. For example, elderly individuals tended to have more difficulty in speech perception than younger participants even when their absolute hearing thresholds were matched to that of the younger participants [13-15]. Also, as noted above, Humes [21] reported that the second factor accounting for the variance in the performance of speech perception tasks by hearing aid wearers was non-verbal IQ and age. Some researchers have viewed these findings as further evidence for one of the more popular recent theories in aging research, that posits that as individuals age, there is a generalized slowing of brain/cognitive functioning.

The putative slowing of cognitive processing is reflected in an almost linear decline in problem solving, reasoning, memory and language from early adulthood to senescence [22,44-47]. Age-related deficits in working memory, executive functioning, the ability to maintain a goal, or processing speed have been suggested as the causes responsible for the difficulties in speech perception in the elderly [5,22,28,29,48]. Age-related changes in one or more of the executive control components (working memory, attention, or goal maintenance) could contribute to a reduction of the overall cognitive functioning in the elderly, and consequently lead to difficulties in successfully performing complex tasks, including speech perception [e.g., 27,30].

In the present study, we attempted to assess the effect of age on speech perception while controlling for the possible decline of cognitive function by two procedures: 1) pre-selection screening; and 2) by direct testing and inclusion of scores on cognitive tests in the data analyses. First, the candidates for the study who were over 60 years of age were pre-screened with the Mini Mental State Examination (MMSE) [32]. Only individuals with scores
of 29-30, reflecting a high level of mental ability, were included in the subject sample.

Second, all participants were tested on the WAIS-III matrices and digit span tests. The results indicated that, for the population sampled in this study, there was no significant age-related decline in these cognitive abilities. These test scores were also entered in all of the regression analyses of speech perception. The results of the regression analyses indicated that performance on the WAIS-III matrices and digit span tests did not add significantly to the explained variance and, therefore, did not predict performance on any of the speech perception tasks. In contrast, age as a variable, independent of hearing thresholds and scores on the digit span and matrices tasks, did significantly add to the explained variance (7.6%) when words were presented against background speech noise and when speech was time-compressed (5%). Apparently, when words are presented against background speech noise or when speech is compressed, a significant decline in speech perception with age can be found even when working memory and reasoning are intact and unchanged over the life span.

These suggest that there are other factors associated with aging, other than changes in hearing thresholds and in cognitive functioning, may be involved in the age-related decline in speech perception when speech is presented in speech noise and when speech is time-compressed. Perceiving speech when words were presented against a speech noise background and when speech was time-compressed were not the two most difficult of the experimental conditions. In fact, when comparing the accuracy of speech perception between all four conditions, speech against a white noise background was clearly the most difficult condition. However, although it was the most difficult of the tasks, the amount of explained variance accounted for by increases in hearing thresholds was less (10.1%) than when speech was presented against a speech noise background (19.5%) (Tables 3-5). Yet under the white noise background condition, age, as an independent variable was not significant in predicting a decline in speech perception.
In summary, we found that under the conditions of the present study, change in hearing thresholds for short duration sounds was the major factor in predicting a decline in speech perception, when words are presented against a white noise or speech noise background, even when all individuals were within the normal range for their age groups. In an aging population, screened for intact cognitive functioning and whose level of cognitive performance was equivalent to the younger participants, cognitive functioning was not predictive of a decline in speech perception. Under two of the conditions in the present experiment, i.e., when words were presented against a speech noise background and when speech was time-compressed at 60% rate, age, as an independent variable, significantly predicted a decline in speech perception even when hearing sensitivity and cognitive functioning were controlled.

The authors have no conflict of interests.
References


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<td>Click train</td>
<td>0.65***</td>
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<tr>
<td>1 kHz pure tone, 15msec duration</td>
<td>0.28**</td>
</tr>
<tr>
<td>1 kHz pure tone, 50msec duration</td>
<td>-0.02</td>
</tr>
<tr>
<td>1.8 kHz pure tone, 15msec duration</td>
<td>0.55***</td>
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**p<.01; ***p<.001;

$\alpha = .01$ after Bonferroni’s correction for multiple comparisons was applied
### Table 2. Hierarchical Linear Regressions Predicting Speech Perception in Quiet

<table>
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<tr>
<th>Step</th>
<th>$\beta$</th>
<th>$t$</th>
<th>$R^{2}_{cha}$</th>
<th>$F_{cha}$</th>
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<tbody>
<tr>
<td>Step 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Click</td>
<td>-.227</td>
<td>-1.357</td>
<td>0.51</td>
<td>1.505</td>
</tr>
<tr>
<td>1 kHz tone, 15msec</td>
<td>.234</td>
<td>1.922</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.8 kHz tone, 15msec</td>
<td>.123</td>
<td>.784</td>
<td></td>
<td></td>
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<tr>
<td>Step 2</td>
<td></td>
<td></td>
<td>.006</td>
<td>.243</td>
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<tr>
<td>Digit Span</td>
<td>-.077</td>
<td>-.65</td>
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<tr>
<td>Matrices</td>
<td>.053</td>
<td>.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>-.069</td>
<td>-.480</td>
<td>.003</td>
<td>.230</td>
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*Full model: $R^2 = .059$, $F(6,81) = .851$, $p > .05$*
### Table 3. Hierarchical Linear Regressions Predicting Speech Perception in White Noise

<table>
<thead>
<tr>
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<th>$t$</th>
<th>$R^2_{cha}$</th>
<th>$F_{cha}$</th>
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<tr>
<td>Step 1</td>
<td>.101</td>
<td>3.135*</td>
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<tr>
<td>Click</td>
<td>-.121</td>
<td>-.756</td>
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<tr>
<td>1 kHz tone, 15msec</td>
<td>-.280</td>
<td>-.236*</td>
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<td></td>
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<tr>
<td>1.8 kHz tone, 15msec</td>
<td>.082</td>
<td>.538</td>
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<td>Step 2</td>
<td>.026</td>
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<td>Digit Span</td>
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<tr>
<td>Matrices</td>
<td>.154</td>
<td>1.346</td>
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<tr>
<td>Step 3</td>
<td></td>
<td></td>
<td>.001</td>
<td>.139</td>
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<tr>
<td>Age</td>
<td>-.052</td>
<td>-.373</td>
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* $p < .05$

*Full model: $R^2 = .128$, $F(6, 81) = 1.976, p > .05$*
<table>
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<tr>
<th>Step</th>
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<th>$R^2_{cha}$</th>
<th>$F_{cha}$</th>
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</thead>
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<tr>
<td>Step 1</td>
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<td>.195</td>
<td>6.792***</td>
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</tr>
<tr>
<td>Click</td>
<td>-.402</td>
<td>-2.647**</td>
<td></td>
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<tr>
<td>1 kHz tone, 15msec</td>
<td>-.049</td>
<td>-.437</td>
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<td></td>
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<tr>
<td>1.8 kHz tone, 15msec</td>
<td>-.018</td>
<td>-.127</td>
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<td></td>
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<td>Step 2</td>
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<td>.010</td>
<td>.506</td>
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<td>Digit Span</td>
<td>.105</td>
<td>.983</td>
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<td>Matrices</td>
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<td>-.533</td>
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<tr>
<td>Step 3</td>
<td></td>
<td>.076</td>
<td>8.570**</td>
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<td>Age</td>
<td>-.367</td>
<td>2.928**</td>
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* $p < .05$, ** $p < .01$, *** $p < .001$

*Full model: $R^2 = .281$, $F (6, 81) = 5.279$, $p < .001$*
### Table 5. Hierarchical Linear Regressions Predicting Speech Perception for Speech Compressed at 60% Compression Rate

<table>
<thead>
<tr>
<th>Step</th>
<th>β</th>
<th>t</th>
<th>$R^2_{cha}$</th>
<th>$F_{cha}$</th>
</tr>
</thead>
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<tr>
<td>Step 1</td>
<td></td>
<td></td>
<td>0.067</td>
<td>2.02</td>
</tr>
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</table>

- Click: $0.179$, $t = 1.093$

1 kHz tone, 15msec:
- $β = -0.292$, $t = -2.418^*$

1.8 kHz tone, 15msec:
- $β = -0.054$, $t = -0.351$

| Step 2 |       |       | 0.011       | 0.510     |

- Digit Span: $-0.017$, $t = -0.148$
- Matrices: $-0.105$, $t = -0.892$

| Step 3 |       |       | 0.050       | 4.62*     |

- Age: $-0.297$, $t = -2.148^*$

* $p < .05$

**Full model**: $R^2 = 0.128$, $F(6,87) = 1.99$, $p > .05$
Table 6. Means (percept correct) and Standard Deviations of Accuracy Rates for Speech Perception by Speech Condition

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>SD</th>
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</thead>
<tbody>
<tr>
<td>Speech in quiet</td>
<td>.985&lt;sub&gt;a&lt;/sub&gt;</td>
<td>.041</td>
</tr>
<tr>
<td>Speech in speech noise</td>
<td>.859&lt;sub&gt;b&lt;/sub&gt;</td>
<td>.087</td>
</tr>
<tr>
<td>Speech in white noise</td>
<td>.710&lt;sub&gt;c&lt;/sub&gt;</td>
<td>.090</td>
</tr>
<tr>
<td>60% compressed speech</td>
<td>.959&lt;sub&gt;d&lt;/sub&gt;</td>
<td>.029</td>
</tr>
</tbody>
</table>

*Note:* Means with different subscripts are significantly different (*p* < .05).
Figure 1. Speech perception accuracy (percent correct) by age for four conditions used in the study: A. Speech perception in quiet; B. Speech perception in speech noise; C. Speech perception in white noise; D. Time-compressed speech perception in 60% compression rate.