Temporal and non-temporal processes in the elderly

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ABSTRACT

Background: The present study examined whether the reported age-related decline in auditory temporal resolution is specific to the temporal domain or rather reflects a general decline in auditory perception, including the stimulus intensity domain as well.

Method: The performance of 89 healthy participants aged between 21-82 years with normal hearing was tested on a variety of psychophysical tasks, where discrimination was based either on the temporal or the intensity domains. Stimulus levels for all tasks were 40 dB SL (corrected for threshold). Participants were also tested on two cognitive tasks: WAIS III matrices and digit span.

Results: Findings indicate that age was significantly negatively correlated with performance on three of the temporal resolution tasks, namely dichotic temporal-order judgment, spectral temporal -order judgment, and gap detection, but not on the intensity discrimination task, thus emphasizing the specificity of the age-related decline to the auditory temporal domain.

Conclusions: The overall results suggest that age-related changes in auditory perception are specific to the temporal domain, even when controlling for hearing sensitivity and cognitive ability, and are not reflected in other aspects of non-temporal perception, such as intensity discrimination.

Keywords: Aging, Auditory temporal processing, Non-temporal processing
INTRODUCTION

A common complaint among the elderly is a difficulty in understanding speech, especially under less favorable conditions, such as when speech is accompanied by noise or when speech is rapid. Several theories have been presented to explain this age-related difficulty in comprehending speech. Since aging of otherwise healthy individuals is accompanied by changes in a variety of peripheral and central physiological, behavioral and cognitive functions, some of the theories have suggested that these changes are associated with the reported difficulty in understanding speech. For example, the hearing-sensitivity theory argues that presbycusis and other age-related changes in peripheral hearing are the main causes for the difficulties in speech comprehension reported by the elderly [1-3]. However, a number of reviews and studies have shown this explanation to be insufficient since correction for audiometric hearing loss does not always solve the problem fully [4,5].

An alternative explanation for the difficulties in speech comprehension by the elderly emphasizes age-related changes in cognitive processes. The cognitive processing approach posits that age-related deficits in working memory, executive functioning, and/or processing speed are responsible for difficulties in speech comprehension in the elderly [6-11].

Over the past two decades, some researchers have begun to focus on age-related degradation in auditory temporal resolution as an explanation for speech comprehension difficulties observed in the elderly. The rationale underlying this hypothesis is that the appropriate use of speech cues relies on several types of auditory temporal resolution [3, 11-13], which have been shown to decline with aging. For example, several studies have shown that older adults perform poorer than younger adults in gap detection tasks and need longer silent intervals to identify the presence of a gap when the marker signal is 250ms or shorter [14-18]. Other studies have reported that older participants have difficulty in correctly
identifying temporal order in a tonal sequence [19,20]. A number of studies have reported that older individuals require larger differences in duration between two tones in order to detect a difference in duration [e.g., 21]. Similar results, indicating poorer discrimination, were found when comparing older and younger adults on binaural temporal processing tasks such as tone localization [22], and click lateralization [e.g., 23].

Although the psychophysical studies cited above provide strong evidence for deficits in auditory temporal resolution as individuals age, the nature of this relationship has not been completely clarified. Given the large number of reports showing general deficits in cognitive processing by the elderly, a question may legitimately be raised as to whether the reported difficulty in auditory temporal resolution in the elderly is specific to the time domain (i.e., a specific difficulty in temporal resolution) or whether this deficit merely reflects the finding of general age-related perceptual and cognitive deficit. To our knowledge, although a large number of studies report age-related decline in temporal resolution, there has been no systematic study reported to date that compared auditory temporal resolution and non-temporal resolution, such as intensity discrimination, in the same groups of young and old normal hearing participants, while controlling for peripheral and cognitive changes. Several earlier studies did address some of the aspects of this question. For example, Humes and Christopherson [24] reported testing a group of hearing impaired older participants and a group of young normal participants under quiet conditions and under noise-masked conditions on temporal resolution and intensity discrimination. In another study, Humes et al. [2] tested only elderly participants on the same auditory test battery used in the earlier study, that included temporal and intensity discrimination tasks. They analyzed the results by Principal Component Analysis and found that performance of the elderly participants on the intensity task was not included in the same factor as performance on the temporal resolution tasks. These results perhaps do suggest that performance on intensity discrimination and temporal
resolution by the elderly reflects different perceptual/cognitive processes. However, what seems to be missing to date is a direct comparison between discrimination based on the auditory temporal dimension and discrimination based on a non-temporal dimension (e.g., intensity) in the same subject population.

The present study was designed to address this issue directly. Specifically, we tested whether the reported age-related reduction in temporal resolution reflects a domain-specific deficit or whether it reflects a more general deterioration of the auditory perceptual system. If the former explanation is correct, then, after controlling for differences in hearing sensitivity and cognitive performance, the age-related deficits will be found only in discrimination tasks dependent upon temporal resolution. If the alternative explanation is correct, then an age-related deficit will also be found in discrimination tasks dependent upon non-temporal resolution.

In the current study we used several psychophysical tasks to study temporal and non-temporal auditory processing. Temporal processing was tested by three psychophysical tasks. One of the tasks have been used previously in a number of studies of aging and auditory temporal processing, i.e., the gap detection [e.g., 17,25]. Two other tasks of temporal order resolution were added: 1) dichotic and 2) spectral temporal order judgments. These tasks have been found to be sensitive to language processing [26-28]. All participants were also tested on one auditory psychophysical task based on intensity discrimination: supra-threshold intensity discrimination [e.g., 5,29].

In order to eliminate two confounding factors most associated with aging, we also controlled for age-related changes in hearing sensitivity [11,30] and possible differences in cognitive function [3,31].
METHOD

Participants

Eighty nine participants participated in the study, 46 (52%) females and 43 (48%) males, aged 21 to 82. Age and sex were distributed fairly equally (Table 1). No correlation was found between age and years of education (r=-.11, p>.05). All participants were screened using hearing norms per aging criteria by Lebo and Reddell [32], and had interaural threshold differences less than 10 dB. Hearing screening was done for .5, 1, 2, and 4 kHz, and those who were within their age norms, specified for every 5 years, were included in the study. All participants 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) [33]. All scores were 29-30 reflecting a high level of mental ability.

Tasks and stimuli

Participants were tested on four psychophysical tasks, of which three were based on temporal processing (i.e., dichotic temporal order judgment (TOJ), spectral TOJ, gap detection), and one based on non-temporal processing (i.e., intensity discrimination). In addition, participants performed two cognitive tasks (i.e., matrices and digit span).

To control for individual and age-related differences in hearing sensitivity, the intensity of the stimuli was set individually for each participant, based on his or her absolute threshold for that stimulus, as follows: For each participant, the thresholds for the 1 kHz 15ms duration tone, 1 kHz 50ms duration tone, and 1.8 kHz 15ms duration tone were first determined. Rise and fall time for all pure tone stimuli were 2ms. The stimuli were then presented at an intensity level of 40 dB above the individual's threshold (40 dB SL). By using this procedure, we equated the signal levels for all participants relative to their individual
thresholds. The specific parameters for each of the tasks were determined by a number of pretests that yielded the most reliable psychometric curves. All tasks were performed in a double door semi-anechoic chamber with attenuation of 30 dB.

**Absolute thresholds.**

Absolute thresholds for the stimuli presented in the psychophysical tests (1 kHz pure tone 15ms duration, 1 kHz pure tone 50ms duration, and 1.8 kHz pure tone 15ms duration) were measured using a 2-alternative, forced-choice adaptive threshold paradigm with a two-down-one-up methodology [34]. Three blocks of stimuli were presented to each participant. 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. Table 1 presents thresholds by age groups.

**Dichotic temporal order judgment (TOJ).**

On each trial participants were presented with a pair of 15ms duration 1.8 kHz tones, presented dichotically, i.e., the first tone to one ear the second tone to the other ear. Participants were required to reproduce the order in which they heard the tones (left first then right; or right first then left). Tone combinations were presented in a random order with the inter-stimulus interval (ISI) =5, 10, 15, 30, 60, 90, 120 and 240ms. The order of the presentation of ISIs was also random. Each ISI value was repeated 16 times, resulting in a total of 256 trials. After every 32 trials participants received a short recess. Percent correct was recorded for each participant for each ISI.

The experiment was done following a four-steps training. Step 1 was done in order to familiarize the participants with the tones. The participants were first presented with six
examples of tone in one ear, then six examples of the tone in the other tone. In step 2, the training proceeded with 24 trials, 12 for stimulus in each ear, randomly intermixed. On each trial, the participant was required to identify the sound location by pressing the correct key. Visual feedback (“correct”/“incorrect”) was provided for each response. In step 3, the stimuli were presented in random order, with no feedback, until the participant met the criterion of 20 correct responses in 24 consecutive trials. All participants reached this criterion. In step 4, participants were presented with 16 pairs of stimuli in two possible patterns: left-right, right–left, with ISIs of 240 and 60ms, resulting in 64 pairs of stimuli. Participants were to identify which pattern they heard by pressing the key for the first sound followed by the key for the second sound. Visual feedback was provided on all training trials. No feedback was provided during the experimental session [26].

*Spectral TOJ.*

On each trial participants were presented with a pair of 15ms duration 1 kHz (low) and 1.8 kHz (high) tones, presented diotically, i.e., the same stimulus pair was presented to both ears simultaneously. Participants were required to reproduce the order in which they heard the tones (high before low or low before high). Tone combinations were presented equally in a random order with ISI=2, 5, 10, 15, 30, 60, 90, 120, and 240ms. The order of the presentation of the ISIs was also random. Each ISI value was repeated 16 times for a total of 288 trials. After every 32 trials participants were given a short recess. Percent correct was recorded for each participant for each ISI.

The experiment was done following a four- steps training. Step 1 was done in order to familiarize the participants with the tones. The participants were first presented with six examples of one tone, then six examples of the other tone. In step 2, training proceeded with 24 trials, 12 for each stimulus, randomly intermixed. On each trial, the participant was
required to identify the sound by pressing the correct key. Visual feedback ("correct"/"incorrect") was provided for each response. In step 3, the stimuli were presented in random order, with no feedback, until the participant met the criterion of 20 correct responses in 24 consecutive trials. All participants reached this criterion. In step 4, participants were presented with 16 pairs of stimuli in two possible patterns: low-high, high-low, with ISIs of 240 and 60ms, resulting in 64 pairs of stimuli. Participants were to identify which pattern they heard by pressing the key for the first sound followed by the key for the second sound. Visual feedback was provided on all training trials. No feedback was provided during the experimental session [26].

**Gap detection.**

On each trial participants were presented with a pair of two 50ms duration, 1 kHz pure tones, separated by a 100ms inter-stimulus interval (ISI). Each pair contained a target tone with a gap of silence that ranged between 0.5 to 36ms, and a reference tone with a gap of 0ms. This procedure of using a gap in both the reference and target tones was adapted in order to prevent judgments based on possible perceived changes in the overall envelope of a tone with a gap versus a tone with no gap (see Schneider et al., 1994). Participants judged which of the two tones contained the gap. Gap durations were 0.5, 1, 2, 4, 8, 12, 18, 24, and 36ms, and were presented randomly 16 times each, for a total of 144 trials. After every 32 trials participants received a short recess. Percent correct was recorded for each participant for each ISI. The experimental session was preceded by a practice session including 36 and 18ms gaps that were repeated 16 times each. In this practice session, participants received feedback for each response. No feedback was provided during the experimental session.

**Intensity discrimination.**
On each trial participants were presented with a pair of 500 ms duration, 1 kHz pure tones, separated by 100ms. In each pair, one tone was presented at 40 dB above hearing level (40 dBSL), and the other tone was presented .25 to 12 dB below 40 dBSL. Participants were required to indicate whether the two tones in each pair were the same or different in intensity. Tone intensity deltas were .25, .75, 1.5, 2, 4, 6, 8, 10, and 12 dB and were presented randomly 16 times each, for a total of 144 trials. After every 32 trials participants received a short recess. Percent correct was recorded for each participant for each ISI. The experimental session was preceded by a practice session in which practice stimulus pairs were presented with intensity deltas= 12, 6 and 0 dB. The practice stimulus pairs were repeated 16 times each. In the practice session, participants received feedback for each response. No feedback was provided during the experimental session.

Cognitive ability.

Cognitive ability was measured using the Hebrew version of the Wechsler Adult Intelligence Test (WAIS-III) matrices and digit span tests [35].

Apparatus

All the psychophysical tasks were presented using a PentiumI personal computer that controlled the stimulus presentation and recorded responses and response time. All of the auditory stimuli used in the various psychophysical tasks were generated by a sound-generator device (TDT-system II: Tucker-Davis Technologies, Gainesville, FL), and then presented binaurally through TDH- 49 headphones. Tasks were programmed using Matlab™ software version 6.5.

Screening for hearing sensitivity was performed using Danplex DA64 or Maico Hearing Instruments Ltd MA32 audiometers.
Procedure

The data presented in the current paper is part of a larger experiment that was carried out in two sessions, of two and one 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 in order to determine the intensity of the stimuli to be presented in the psychophysical tasks. The first session was preceded by the screening procedure, during which participants were informed regarding the nature of the testing procedure and then signed an informed consent. Participants filled out a personal questionnaire, underwent audiometric testing and then performed the MMSE. All participants were paid an amount in NIS equivalent to $50 for participating in the study. Prior to the experimental procedure, participants received full explanation about the study and signed written informed consent. The study was approved by the University Institutional Review Board.

RESULTS

Two different dependent variables for the psychophysical tasks were analyzed and are presented in this section: 1) thresholds for the tasks that tested the hearing sensitivity-age relationship; and 2) overall percent correct for the other tasks that tested the age effect in auditory function. Whereas for the hearing sensitivity tasks, all of the 89 participants provided reliable threshold data, a number of participants were unable to achieve sufficiently stable performance in some of the other psychophysical tasks at the stimulus values yielding 75% or 50% correct performance (depending on the task). This may have been due to the fact that we used different procedures for the different tasks. The issue of different procedures is discussed
below. Thus, while the percent of participants yielding reliable thresholds in some of the psychophysical tasks that tested for age effects in supra-threshold auditory function was around 95%, in other tasks the percent was reduced to below 90%. In one task, spectral TOJ, the majority of participants (over 70%) were able to correctly identify the temporal order of the high versus low frequency tones at 75% or greater even at inter-stimulus-intervals of less than 5ms, making the differential threshold incalculable. Were we to use threshold data, we would have been forced to reduce the number of participants in the analysis. However, by using the overall percent correct data as the dependent variable, which were available for almost all of the participants in all of the psychophysical tasks, we were able to use all of the data and make some meaningful inter-task comparisons.

Furthermore, since age was a continuous variable in the design of the study, all of the data were analyzed by regression analyses. For all of the statistical analyses, probability levels were adjusted according to Bonferroni’s formula [36].

1. Age and Hearing Sensitivity

Age was significantly related to hearing sensitivity for the 15ms duration 1 kHz pure tone (r=.28, p<.001) and the 15ms duration 1.8 kHz pure tone (r=.55, p<.001), as measured by the absolute threshold task. However, the threshold of the 50ms duration 1 kHz tone was not significantly reduced by age (r=-.02, p>.05, see Table 2).

2. Age and Cognitive Ability

Cognitive ability, as measured by the digit span test and matrices was not found to correlate significantly with age (Table 2). These results indicate that for the population sample in this study, there was no significant difference in these cognitive abilities between the younger and older participants.
3. Age and Auditory Temporal and Non-Temporal Resolution

The main aim of the study was to test whether the reported age related deterioration in temporal resolution is domain-specific (i.e., related to temporal resolution only) or whether it reflects the reported general decline in auditory perceptual and cognitive functioning, while controlling for peripheral and cognitive changes, which will then be resulted also in age-related decline in non-temporal resolution tasks, such as intensity discrimination.

In order to test the hypothesis that age predicts deficit in auditory temporal resolution, and that this deficit is not a mere result of a general deterioration with age in cognitive ability and in auditory perception, four hierarchical regressions were conducted to predict performance on the four psychophysical tasks, while controlling for hearing sensitivity and cognitive ability. In each regression, the dependent variable was level of performance accuracy while hearing sensitivity, scores on the digit span and matrices tasks, and age were the predicting variables. Because both hearing sensitivity and cognitive performance are related to age, they were entered to the regression before age so we could test the net effect of age on auditory performance. Since changes in hearing sensitivity are physiological, hearing threshold of the stimulus used in each task (1.8kHz, 15ms tone for dichotic TOJ; 1.8kHz and 1kHz, 15ms tones for spectral TOJ, and 1kHz, 50ms tone for gap detection and intensity discrimination tasks) was entered on Step 1, and cognitive ability, namely the scores on digit span and matrices, were entered on Step 2. Accordingly, age was entered on Step 3. Zero-order correlations among the study variables appear in Table 2. The outcomes of these regressions appear in Tables 3-6. Inspection of Tables 3-6 indicates that, after controlling for hearing sensitivity and cognitive ability, age made a significant (negative) contribution in predicting performance accuracy on Dichotic TOJ, spectral TOJ, and gap detection only, such that as participants age, performance accuracy declined. Age made no significant contribution to the prediction of performance accuracy on intensity discrimination, Two
examples of the raw data, i.e., performance accuracy as a function of age are shown for the gap detection and intensity discrimination tasks are shown in Figures 1 and 2.

DISCUSSION

The main results of the study indicated that of the four psychophysical tasks, three based on temporal resolution and one on non-temporal resolution, age was significantly associated with decline in performance on the temporal resolution tasks (dichotic TOJ, spectral TOJ, and gap detection) even after controlling for differences in individual hearing thresholds and performance on the matrices and memory cognitive tasks. Aging was not related to performance on the non-temporal resolution task, namely, intensity discrimination. Furthermore, intensity discrimination was not significantly predicted by hearing thresholds or by performance on the two cognitive tasks.

Aging has been reported to be associated with deficit in auditory temporal discrimination by a number of researchers over the last decade [e.g., 3,13,17]. However, since non-temporal resolution tasks usually were not studied in the context of aging, there is not enough evidence to conclude from current studies that the temporal domain is more sensitive to aging than other auditory domains. The major purpose of the present study was to test the hypothesis that auditory discrimination based on the temporal domain is more sensitive to aging than discrimination based on a non-temporal domain, such as intensity discrimination. The findings of the present study provide support for the hypothesis that the auditory temporal domain is relatively more sensitive to aging than a comparable auditory non-temporal domain, such as intensity discrimination.

In the present study, all stimuli were presented at the same supra-threshold level corrected for each participant’s threshold for that particular stimulus and statistically controlled in the analyses. Therefore, the finding of an age-related decline in performance in
the auditory temporal domain implies that this effect is apparently unrelated to the general decline in sensory/perceptual processes found in older individuals. Several earlier studies had suggested that since the decline in auditory sensitivity found in the elderly may be associated with the reported decline in temporal resolution, this parameter can be controlled by pre-selecting participants for their studies whose hearing thresholds fell within the range of the norms for each age group [13,15,25,37]. Some researchers selected their participants such that the younger and the older participants were matched for hearing sensitivity [1,38]. Other researchers tested two groups each of younger and older participants, those with normal hearing and those with impaired hearing [e.g., 19]. These three solutions may not fully control for the problem of age-related changes in hearing sensitivity: The first procedure does not equate all participants at the same level of stimulation and thus may not fully control for differences in hearing sensitivity, the second solution limits the generalizability of the findings to groups of younger and older individuals whose hearing thresholds are equal. The problem with the third procedure is the difficulty in finding younger participants with a sloping high frequency loss similar to that of older participants [39]. In the present study we combined three methods for controlling for age-related differences in hearing sensitivity. First we screened the participants for hearing level, so only participants with hearing level appropriate for age were recruited for the study. Second, we presented the stimuli at the same supra-threshold level for each individual relative to his or her threshold (i.e., dB SL), and third, we statistically controlled for threshold differences by entering hearing thresholds in the regression analyses. Our findings of a significant age-related decline in the three temporal resolution tasks coupled with a lack of significance in the non-temporal task, despite the correction for hearing thresholds in all the tasks, further emphasizes the specific sensitivity of the temporal domain to aging.
Several earlier studies also reported age-related difficulty in auditory temporal resolution when differences in hearing thresholds were either not found to be significant [e.g., 19] or controlled for by covariate techniques [39]. The results of those and of the current study serve to refute the hypothesis that age-related decline in temporally based auditory discrimination tasks can be fully explained by age-associated increases in hearing thresholds [e.g., 40,41].

An additional aspect of this study relates to the influence of cognitive functioning on performance in the psychophysical tasks used to test for a decline in temporal resolution with aging. Participants in the present study were also tested on two cognitive functions: memory (digit span) and matrices. The results show no significant effect of aging on either cognitive task. Nevertheless we found that cognitive performance was significantly related to temporal resolution. Higher scores on the digit span and the matrices tasks were correlated with higher scores on the psychophysical tasks independent of the age of the participants. Therefore, we statistically controlled for level of cognitive functioning when analyzing the age-related changes in temporal resolution. The age-related decline in performance was found to be significant even after controlling for cognitive ability. The present findings, demonstrating that even after controlling for cognitive functioning there was a significant effect of age on temporal resolution, strengthen the argument that the auditory temporal domain is sensitive to aging.

Although we have no direct evidence we might suggest some relation between these findings and deficits in speech comprehension in the elderly. Normal speech is produced at approximately 150 to 250 words per minute, i.e., 4 to 7 syllables per second [42]. Accordingly, syllable duration ranges between 67 to 177ms [43]. Vowel duration ranges between 70 to 130ms [43], and consonant duration ranges between 5 to 40ms [44]. The temporal separations necessary for accurate identification of two stimuli (gap detection) and
for the correct identification of the temporal order of two stimuli in the spectral and dichotic
TOJ tasks range between 5-75ms [26]. The findings of the present study that aging is
associated with a significant reduction in accuracy in the three tasks for which the separation
of stimuli necessary for correct discrimination is in approximately the same temporal range
(5-75ms) as the duration of consonants, vowels and short syllables lends support to earlier
findings and suggestion of a more general age related decrement in auditory temporal
resolution as a basis for the difficulty in speech comprehension reported by the elderly [45].

In summary, in the present study, we demonstrated the relationship between aging and
temporal resolution in participants with age appropriate hearing and no cognitive deficits,
while controlling for performance on cognitive tasks and on differences in hearing thresholds.
We hypothesized that auditory tasks based on temporal resolution would be more sensitive to
aging than tasks based on intensity discrimination. The main results of the study indicated that
age was significantly correlated with temporal resolution tasks (gap detection, spectral and
dichotic TOJ). The hypothesis was, thus, supported by the results. Future studies should be
directed toward a more systematic test of this hypothesis and its relevance to age-related
decline in speech comprehension. These findings together with those reported in the earlier
literature may contribute to a better understanding of the age-related difficulties by the elderly
in understanding speech.
The authors have no conflict of interests.
REFERENCES


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<th>Age</th>
<th>N</th>
<th>% females</th>
<th>1 kHz pure tone, 15ms duration</th>
<th>1 kHz pure tone, 50ms duration</th>
<th>1.8 kHz pure tone, 15ms duration</th>
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<td>71-82</td>
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Table 2. Zero-Order Correlations among Study Variables

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<td>5. Dichotic TOJ</td>
<td>-.27*</td>
<td>.03</td>
<td>-.11</td>
<td>-.16</td>
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<td>8. Intensity discrimination</td>
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<td>.03</td>
<td>.26*</td>
<td>.25*</td>
<td>.30**</td>
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<td>.20</td>
<td>.17</td>
<td>.38**</td>
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<td>.25*</td>
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<td>.09</td>
<td>.33**</td>
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*p < .05; **p < .01; ***p < .001
Table 3. Hierarchical Linear Regression Predicting Dichotic TOJ

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<th>β</th>
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<th>( F \text{cha} )</th>
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<td></td>
<td></td>
<td>HT 1.8 kHz, 15ms</td>
<td>-.17, -.01, 1.56</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.10</td>
<td>4.74*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 2</td>
<td></td>
<td></td>
<td></td>
<td>Digit Span</td>
<td>.10, .01, .90</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.27</td>
<td>2.50*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 3</td>
<td></td>
<td>.05</td>
<td>4.62*</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>-.26</td>
<td>2.15*</td>
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</tr>
</tbody>
</table>

* \( p < .05 \)

HT- Hearing Threshold; Full model: \( R^2 = .17, F (4, 84) = 4.32, p < .01 \).
Table 4. Hierarchical Linear Regression Predicting Spectral TOJ

<table>
<thead>
<tr>
<th>Step 1</th>
<th>β</th>
<th>B</th>
<th>t</th>
<th>$R^2_{cha}$</th>
<th>$F_{cha}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>HT 1 kHz, 15ms</td>
<td>-.11</td>
<td>-.01</td>
<td>.92</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HT 1.8 kHz, 15ms</td>
<td>-.09</td>
<td>-.01</td>
<td>.74</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 2</td>
<td></td>
<td></td>
<td></td>
<td>.06</td>
<td>2.63</td>
</tr>
<tr>
<td>Digit Span</td>
<td>.09</td>
<td>.01</td>
<td>.84</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Matrices</td>
<td>.20</td>
<td>.01</td>
<td>1.77</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 3</td>
<td></td>
<td></td>
<td></td>
<td>.04</td>
<td>4.17*</td>
</tr>
<tr>
<td>Age</td>
<td>-.25</td>
<td>-.01</td>
<td>2.04*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* $p < .05$

HT- Hearing Threshold; *Full model: $R^2 = .13, F (5, 85) = 2.42, p < .05$*
Table 5. Hierarchical Linear Regression Predicting Gap Detection

<table>
<thead>
<tr>
<th></th>
<th>( \beta )</th>
<th>( B )</th>
<th>( t )</th>
<th>( R^2_{cha} )</th>
<th>( F_{cha} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1</td>
<td>.00</td>
<td>.14</td>
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<tr>
<td>HT 1 kHz, 50ms</td>
<td>-.04</td>
<td>.00</td>
<td>.38</td>
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<tr>
<td>Step 2</td>
<td>.11</td>
<td>5.27**</td>
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<tr>
<td>Digit Span</td>
<td>.21</td>
<td>.01</td>
<td>1.95+</td>
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<tr>
<td>Matrices</td>
<td>.20</td>
<td>.01</td>
<td>1.78</td>
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<td></td>
</tr>
<tr>
<td>Step 3</td>
<td>.05</td>
<td>4.57*</td>
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<tr>
<td>Age</td>
<td>-.22</td>
<td>.00</td>
<td>2.14*</td>
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<td></td>
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</tbody>
</table>

\* \( p < .05 \); \** \( p < .01 \)

HT- Hearing Threshold; Full model: \( R^2 = .16, F (4, 83) = 3.93, p < .01 \)
<table>
<thead>
<tr>
<th>Step</th>
<th>β</th>
<th>B</th>
<th>t</th>
<th>$R^2_{cha}$</th>
<th>F_{cha}</th>
</tr>
</thead>
<tbody>
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<td>Step 1</td>
<td>.00</td>
<td>.30</td>
<td>.55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HT 1 kHz, 50ms</td>
<td>.06</td>
<td>.00</td>
<td>.55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 2</td>
<td>.02</td>
<td>.85</td>
<td>.91</td>
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<tr>
<td>Digit Span</td>
<td>.11</td>
<td>.00</td>
<td>.91</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Matrices</td>
<td>.07</td>
<td>.00</td>
<td>.58</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 3</td>
<td>.00</td>
<td>.09</td>
<td>.31</td>
<td></td>
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</tr>
<tr>
<td>Age</td>
<td>.03</td>
<td>.00</td>
<td>.31</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

HT- Hearing Threshold; Full model: $R^2 = .03$, $F < 1$
Figure 1. Accuracy (percent correct) by age in a temporal resolution task (gap detection)

\[ y = -0.0014x + 0.7912 \]

\[ R^2 = 0.0617 \]
Figure 2. Accuracy (percent correct) by age in a non-temporal resolution task (Intensity discrimination)