INTENSITY DISCRIMINATION IN NOISE: EFFECT OF AGING

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Abstract

Intensity discrimination thresholds for a 70 dB SPL, 500-Hz pure tone presented in quiet, broadband, and notched noise were measured for six younger and older adults all with good audiograms using a two-alternative forced-choice paradigm. All six younger adults had smaller thresholds in the broadband-noise compared to the notched-noise condition. The majority of the older adults had much larger thresholds than the younger adults in the broadband-noise condition and there was no significant difference between their thresholds in broadband and notched-noise conditions. This pattern of findings suggests that most of the older adults had difficulty making use of the temporal fine structure cues available in the broadband-noise condition, consistent with a possible age-related decline in temporal synchrony coding.

It is well known that the prevalence of hearing problems increases with age. Older adults have difficulties understanding speech in noise that cannot be readily explained in terms of loss of audibility (for a review see Pichora-Fuller, and Souza, 2003). For decades, researchers have attempted to characterize different types of presbycusis, one of which involves neural degeneration (for a recent review see Mills, Schmiedt, Schulte, and Dubno, 2006). Loss of temporal synchrony, or periodicity coding, seems to be a characteristic of neural presbycusis that could explain their problems understanding speech in noise. Loss of synchrony could also explain why older adults with good audiograms do not perform as well as younger adults do on various psychoacoustic measures that involve periodicity coding, such as monaural frequency discrimination thresholds for low frequencies (e.g., Abel, Krever, and Alberti, 1990; He, Dubno, and Mills, 1998). Another phenomenon that could be affected by an age-related loss in neural synchrony is intensity discrimination for high-level tones presented in noise. The purpose of the present experiment is to investigate whether or not there are age-related differences in high-level intensity discrimination in noise that can be predicted from a hypothesized loss of synchrony coding in auditory aging.

If loudness judgments are based only on energy detection in the cochlea then it would be expected that adding a masking noise would increase the intensity discrimination threshold. Further, it would be expected that a masker with more energy near the target frequency would lead to an equal or larger threshold than a masker with less energy near the target frequency. Accordingly, the increase in the intensity discrimination threshold for a tone masked by a broadband noise should be equal to or larger than that of a tone in a notched noise masker whose spectrum level outside of the notch is the same as that of the broadband noise. Although numerous studies have been conducted over the past century investigating the ability of younger adults with clinically normal audiograms to discriminate intensity differences in quiet (e.g., Knudsen, 1923; Jestaed, Wier, and Green, 1977), there are, to our knowledge, no studies of age-related differences in intensity discrimination in notched and broadband noise.

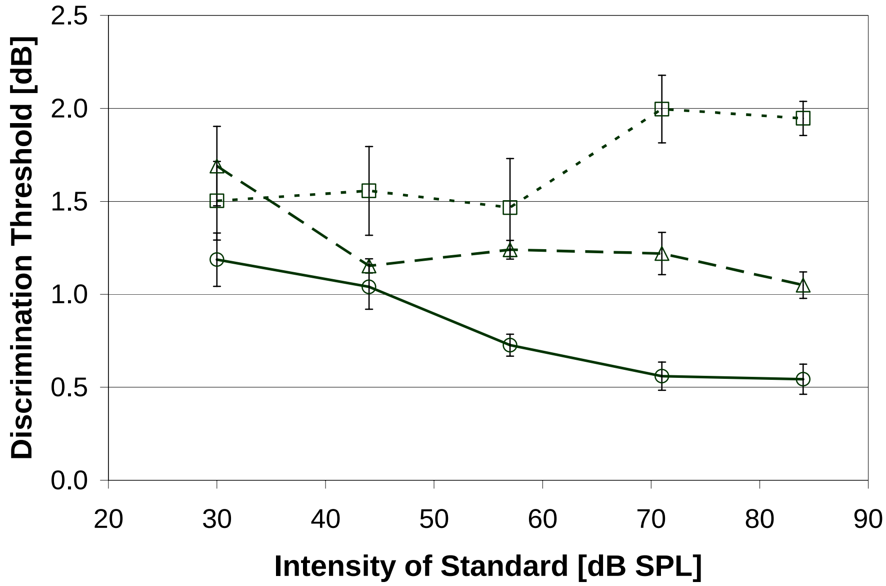

Fig. 1. Intensity discrimination thresholds (75% accuracy) as a function of the level of the standard 1 kHz tone from data published in Schneider and Parker (1990). The thresholds are from three participants listening in three conditions: quiet (circles, solid line), broadband noise (triangles, dashed line), and notched noise (squares, dotted line). Standard error bars are shown.

Schneider and Parker (1990) measured intensity discrimination thresholds of three younger adults with normal audiograms for a 1 kHz tone presented in three conditions: quiet, notched noise, and a broadband noise. The spectrum level of the broadband noise was flat up to 5 kHz and set to 35 dB/Hz below the level of the pure tone. The notched noise background was created in a similar manner, but was passed through a band-stop filter with cut off frequencies of 500 and 2000 Hz. The thresholds for the three participants studied by Schneider and Parker (1990) have been plotted in Figure 1. As shown in the figure, it is clear that as the presentation level of the standard tone is increased, the intensity discrimination thresholds for the quiet and broadband-noise condition decrease, while the thresholds increase or stay the same for the notched-noise condition.

The addition of narrowband noise centered about a pure tone will lead to a sinusoid that appears to be modulated in both amplitude and frequency. The frequency modulation makes the tone sound less pure. The degree of modulation is dependent on the relative levels of the noise and tone. If the noise is held at a constant level then the degree of modulation decreases as the level of the tone is increased. Thus, in the broadband-noise condition, a listener may make use of a purity cue to judge the relative intensity of two tones.

The purpose of the present experiment is to replicate the findings of Schneider and Parker (1990) in younger adults and also investigate possible age-related differences that would provide evidence of disruptions in temporal coding of synchrony. Specifically, a listener with normal synchrony coding should have intensity discrimination thresholds for low-frequency tones presented at high levels that are smaller in a background of broadband noise than in a background of notched noise. In contrast, if the listener has a loss or synchrony, then the thresholds measured in a background of broadband noise are expected to be the same or worse than those measured in notched noise, especially when the standard is a low-frequency tone presented at a high level. As well, the thresholds in broadband and notched noise are likely to be significantly larger than those of a listener with good synchrony coding.

Method

Participants

The participants were six younger adult (mean age of 24.8 years, standard deviation of 2.9) and six older adult (mean age of 70.0 years, standard deviation of 2.9) paid volunteers. The younger adult participants had clinically normal hearing (pure-tone thresholds from 250 to 8000 Hz less than 20 dB HL) while the older adult participants had good audiograms (pure-tone thresholds from 250 to 3000 Hz less than 25 dB HL). All listeners provided informed consent and their rights as participants were protected. The protocol for the study was approved by the institutional ethics review board.

Stimuli and procedure

Intensity difference limens were measured using a two-interval two-alternative forced-choice paradigm. For the quiet condition, a 500-Hz pure tone was presented at 70 dB SPL in one interval and a 500-Hz pure tone was presented at 70 + ΔL dB in the other. For the broadband-noise condition, an independent broadband Gaussian noise (0-10 kHz) was generated for each trial interval and added to the two intervals. The spectrum level of the broadband noise was 30 dB SPL/Hz. For the notched-noise condition, an independent noise was created in the same manner (and with the same spectrum level) as the broadband noise; however, the energy in the frequency range from 250–750 Hz was removed by calculating the FFT, zeroing the appropriate frequency bins, and calculating the IFFT. The duration of each tone was 500 ms and an inter-stimulus interval of 250 ms was used. The listener was asked to choose the interval with the louder and/or purer tone and press the corresponding button on a button box. Feedback was provided by illuminating an LED above the correct response button. Tucker-Davis technology was used for digital to analog conversion and to control levels. All stimuli were presented monaurally to the right ear using Sennheiser HD-265 headphones.

Each listener was tested using a non-adaptive procedure at four levels of intensity differences, ΔL, for each of the three masking conditions (quiet, broadband noise, and notched noise). All participants completed four sessions, with each session lasting about two hours. Each session was separated into three parts corresponding to the three masking conditions. In part one, all participants listened to the quiet condition. In part two, half the participants listened to the condition with broadband noise while the other half listened to the condition with notched noise. In part three, the participants listened to the other noise condition. A short break was taken between each part.

In each part, participants completed five practice runs followed by two test runs. Each practice run had total of 20 trials consisting of a randomized order of five trials at each of the four intensity difference levels. Each test run had a total of 100 trials consisting of 25 trials at each of the four intensity difference levels which were presented in random order.

Results

To ensure that the performance of the participants was stable and not contaminated by learning effects, their overall performance, as defined by the total number of correct trials, combined over all of the practice and test runs for all three conditions, was compared across sessions. In general, the performance of each individual was similar in sessions two, three and four. However, the performance of several participants in the first session appeared to be much lower than their performance in the other three sessions which suggested a learning effect was present in session one. The performance for each participant in the first session was compared to the mean and standard deviation of that individual's performances in the three subsequent sessions. For all the younger participants, the performance in the first session was within one standard deviation of their respective means. For one of the older participants, the performance in the first session was within a standard deviation of that participant's mean performance. However, for five of the six older participants, the performance in the first session was more than four standard deviations below their mean performance. For these participants, the data from their first session was discarded due to learning effects and further analyses were conducted using only the data collected in their final three sessions.

Intensity discrimination thresholds for 79% correct were estimated for each individual in each condition based on 800 trials for the younger participants and the one older participant who did not show a learning effect in session one, and based on 600 trials for the five older participants who did show a learning effect in session one. While the estimated thresholds of the younger participants are clustered closely together, the thresholds in noise of the older adults differed greatly. The thresholds in noise of two of the older participants were within one standard deviation of the mean thresholds of the younger participants. Importantly, the thresholds of the other four other older adults in the two noise masker conditions were more than four standard deviations above the mean thresholds of the younger participants. Thus, there appears to be two sub-groups of older adults: a minority who perform as well in noise as do younger adults (O1), and majority who have more trouble in noise than do younger adults (O2).

To confirm that the order in which the noise conditions were presented had no effect on threshold, a repeated measures ANOVA was conducted with age and presentation order as between-subjects factors and masking condition as a within-subjects factor. No significant main effect of order or interaction with order was found; the smallest p value found was 0.34 for the main effect of order, $F(1,8) = 1.041$. Given the small number of participants in the experiment, the data were collapsed over order in all further statistical analyses.

The younger adults have smaller intensity discrimination thresholds for the tones presented in the broadband noise than for the tones presented in the notched noise condition (see Figure 2). In contrast, for the four older adults who had much larger thresholds in noise (O2), the intensity discrimination thresholds for tones presented in broadband and notched noise are the same. A repeated measures ANOVA using Greenhouse-Geisser corrections with a between-subjects factor of age (young vs. O2) and a within-subjects factor of masker showed that there were significant main effects of age ($F(1,8) = 15.471$, $p = 0.004$) and masker ($F(1.08,8.65) = 19.408$, $p = 0.002$). There was also a significant interaction of masker and age ($F(1.08,8.65) = 6.649$, $p = 0.029$). Given the significant interaction, two separate repeated measures ANOVAs were conducted for each age group. For the younger group, a significant main effect of masker was found ($F(2,10) = 26.872$, $p < 0.001$). Tests of multiple comparisons using the least significant difference method found all three masking conditions to be significantly different from each other at the $p = 0.05$ level. For the older group, a significant main effect of masker was also found ($F(2,6) = 7.993$, $p = 0.2$). While tests of multiple comparisons using the least significant difference method confirmed that the thresholds in the no masker condition were significantly different from those of the broadband and notched noise conditions, there was no significant difference between the thresholds in the two noise conditions ($p = 0.1$).

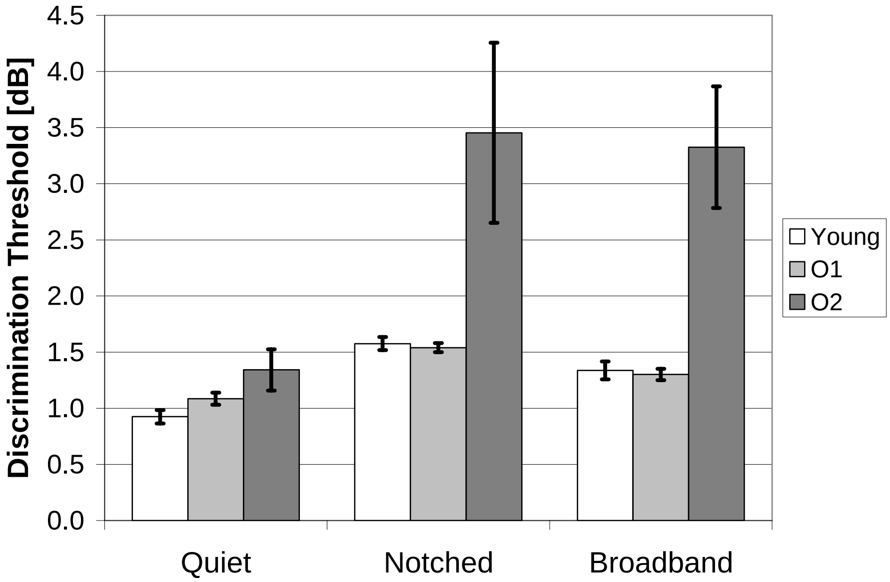

Fig. 2 Average intensity discrimination thresholds (79% accuracy) for younger adults, older adults with good performance in noise (O1), and older adults with poor performance in noise (O2) for the quiet, notched-noise, and broadband-noise conditions. The thresholds of O1 participants in both notched- and broadband-noise conditions were within 1 standard deviation of their younger counterparts. The thresholds of the O2 participants in the two noise conditions were more than 4 standard deviations larger than those of the younger adults. Standard error bars are shown.

Discussion

While there are differences in experimental method, the threshold results for younger adults in the quiet condition in the present study are similar to previously published results (Jestaed et al., 1977; Schneider, and Parker, 1990; He et al., 1998). As well, the smaller thresholds in broadband vs. notched noise observed for the younger adults replicates the findings of Schneider and Parker (1990).

For all of the older adults, the intensity discrimination thresholds in the quiet condition of the present study are smaller, and thus the age-related differences in quiet are much smaller, than the average reported by He et al. (1998). In the He et al. study, intensity discrimination thresholds were obtained from naïve listeners using a maximum-likelihood adaptive procedure, whereas in the present study the measures were obtained using a non-adaptive procedure and listeners who had previous experience with psychoacoustic experiments. The learning effects found in this study for all but one of the older adults suggest that the larger thresholds observed by He et al. may be due to the combination of naïve listeners and the use of a maximum-likelihood adaptive procedure.

Two of the older participants performed as well as the younger adults did in the two noise conditions, while four of the older participants had much larger thresholds. A large age-related increase in variance was also found by He et al. (1998) and it is also common to find greater variance for older than for younger adults on a wide range of auditory and other measures. Whether this heterogeneity in variance reflects the existence of two subpopulations within a population of good-hearing older adults remains to be determined. If so, the apparent grouping of the older participants into two sub-groups may have diagnostic significance with respect to subtypes of presbycusis (Mills et al., 2006).

As mentioned previously, in both the present study and in the study of Schneider and Parker (1990), the younger adults had lower intensity discrimination thresholds for high-level tones presented in the broadband noise than for tones presented in the notched noise. This pattern of results suggests that younger adults make use of temporal fine structure cues to make intensity judgments which requires an auditory system with good synchrony. The important new finding of the present study is that most of the older adults did not perform as well in the noise masker conditions and they demonstrated a different pattern of results insofar as their performance did not differ with the type of noise masker. The finding that their intensity discrimination thresholds in broadband and notched noise were the same suggests that they were not able to make use of the temporal fine structure cues present in the broadband noise condition. Thus, these results seem consistent with an age-related decline in neural synchrony.

Conclusions

There are two main conclusions from this study. First, normal hearing adults are better able to discriminate the intensity of high-level low-frequency pure tones in the presence of a broadband noise than in the presence of a notched noise. This pattern of results suggests that younger adults make use of temporal fine structure cues, at least when cues based on the spread of excitation are limited. Second, despite good performance for tones presented in quiet, some older adults exhibit an age-related increase in intensity discrimination thresholds that is similar in both broadband and notched masking noise. The results for most of the older adults suggest that they were not able to make use of the temporal fine structure cues which is consistent with the hypothesis that a decline in neural synchrony in the auditory system can occur with age.

Acknowledgements

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