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# Duration discrimination in younger and older adults

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# DURATION DISCRIMINATION IN YOUNGER AND OLDER ADULTS

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## ABSTRACT

Ten normal hearing young adults and ten older adults were asked to identify the longer of two sequentially presented tones. The duration of the standard tones ranged from 1.5 ms to 1000 ms across blocks. Duration discrimination was not related to audiometric thresholds. These results show that older adults are much more disadvantaged than young adults when discriminating very short durations (i.e., below 40 ms) that are characteristic of speech sounds, and that this disadvantage cannot be accounted for by hearing levels.

## SOMMAIRE

Nous avon demandé à des sujets jeunes (n = 10) et âgés (n = 10), dont l'acuité auditive est normale, d'identifier la plus longue de deux tonalités. La durée de la tonalité standard variait de 1,5 ms à 1000 ms. Pour un groupe des épreuves, la durée de la tonalité standard ne changeait pas. Le calcul des fractions Weber a demontré que lorsque la durée de la tonalité standard etait moins de 40 ms, les seuils de détection de longueur etaient plus élevés chez les sujets âgés. Mais la difference dans les seuils de détection des jeunes adultes et des personnes âgés a diminuée quand la durée de la tontalité standard augmentait. Éventuellement, à la plus longue durées, les différences entre les groupes d'âge dans les seuils de détection ont disparues. Aussi, les seuils de détection de longeur etaient indépendant de l'acuite auditive. Ces resultats demontrent que les sujets âgés sont plus désavantagés que le sujets jeunes pour discriminer les sons de discours de cortes durée. Ce desavantage ne peut pas être attribué au degré de déficience auditive.

### 1.0 INTRODUCTION

Older adults, even those with little or no hearing loss, often find it difficult to understand speech when the listening situation is less than ideal (e.g., a noisy or reverberant background) or when the rate of speech is high (e.g., Pichora-Fuller, 1997; Pichora- Fuller, Schneider, & Daneman, 1995; Wingfield, Poon, Lombardi, & Lowe, 1985). Because the temporal modulation of the speech signal has been shown to contribute substantially to speech recognition in younger adults (e.g., Kingsbury, Morgan, & Greenberg, 1998; Shannon, Zeng, Kamath, Wygonski, & Ekelid, 1995), several researchers have posited that older adults' speech understanding difficulties might stem, in part, from diminished temporal resolution (e.g., Schneider, 1997; Stuart & Phillips, 1996), although the evidence for this has been mixed. For instance, older listeners who have poor gap duration discrimination abilities have been shown to have more trouble understanding temporally degraded speech (Gordon-Salant & Fitzgibbons, 1993). On the other hand, some studies have suggested that the contribution of age-related changes in temporal resolution to speech recognition are minimal (e.g., Humes, 1996; van Rooij & Plomp, 1990; 1992). It is possible that some of the discrepancies across studies may be due to differences in how temporal resolution was measured.

One paradigm used to investigate temporal processing capacity is duration discrimination. In duration discrimination experiments, listeners are asked to detect a change in stimulus duration. For example, Abel, Krever, & Alberti (1990) measured difference limens (DLs) for changes in stimulus duration in younger normal-hearing adults (20-35 years) and older adults with normal hearing to moderately severe hearing loss (40-60 years). The standard durations of the noise signals were 20 ms and 200 ms, plus 5 ms rise/decay time. The older adults had more difficulty discriminating the signal durations than the younger adults, but performance variability was high. There were no effects of hearing loss or degree of hearing loss. In studies by Fitzgibbons and Gordon-Salant (1994, 1995), when duration DLs were measured for 250-ms tone bursts and 6.4 ms or 250 ms silent intervals between a pair of 250 ms tone bursts, older adults (65-76 years) performed more poorly than younger adults. Moreover, when the stimulus complexity was increased by presenting the target tone bursts within tonal sequences, the performance difference between older

| Duration of Standard | Weber Fractions | |
|---|---|---|
| | Younger Adults | Older Adults |
| 6.4 ms (500 Hz)* | 1.9 | 3.9 |
| 6.4 ms (4000 Hz)* | 2.7 | 4.2 |
| 20 ms (500 Hz) | 0.8 | 1.8 |
| 20 ms (4000 Hz) | 0.6 | 1.3 |
| 200 ms (500 Hz) | 0.3 | 0.4 |
| 200 ms (4000 Hz) | 0.2 | 0.4 |
| 250 ms (500 Hz)** | 0.2 | 0.2 |
| 250 ms (4000 Hz)** | 0.2 | 0.3 |

* Fitzgibbons & Gordon-Salant. 1994
Abel et al., 1990
** Fitzgibbons & Gordon-Salant, 1994; 1995

**Table 1.Approximate duration discrimination Weber fractions (t/t) for younger and older adults across various standard stimulus durations.**

and younger adults also increased (Fitzgibbons & Gordon-Salant, 1995). Once again, hearing loss had no effect on these results.

Although the differences between younger and older adults' duration discrimination skills were significant at the various durations, it is still unclear whether the duration of the stimuli has any effects on younger and older adults' duration discrimination abilities. Table 1 shows a summary of the results of the duration discrimination studies described above, in which duration DL measures have been converted into a Weber fraction so they can be compared across studies. It appears from these rough comparisons that duration discrimination is more difficult at the shorter standard durations (i.e., 6.4 ms and 20 ms) and that this effect is greater for older listeners than younger listeners.

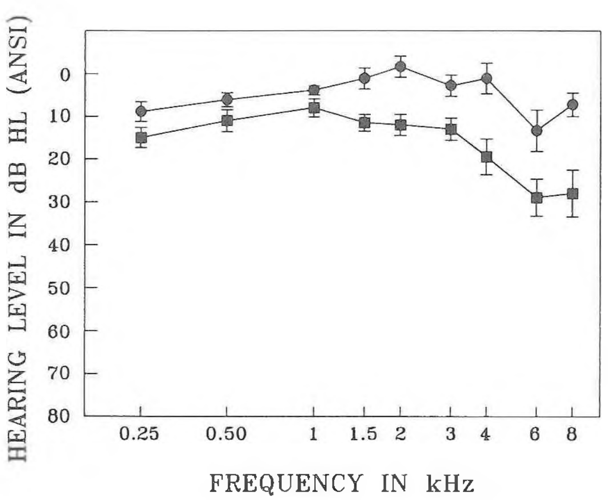


**Figure 1. Average audiograms (left ear) for the younger (circles) and older (squares) adults. Standard error bars are shown.**

In the present experiment, we examined the temporal resolution abilities of younger and older adults in a duration discrimination paradigm in which we systematically varied the standard tone duration from 1.5 ms to 1000 ms. Based on the duration discrimination literature presented previously, we predicted that older adults would perform more poorly than younger adults, and that this age effect would be much more pronounced at short standard tone durations, independent of audiometric thresholds.

## 2.0 METHOD

### 2.1. Participants

Ten younger adults (mean age = 22.3 years; S.D. = 1.6 years) and ten older adults (mean age = 70.9 years; S.D. = 5.7 years) were paid participants in this experiment. Four additional participants (two from each age group) failed to complete all sessions and were excluded from all analyses. The younger adults were students at University of Toronto at Mississauga; the older adults were recruited from a pool of seniors from the local community. All participants had pure-tone, air- conduction thresholds 25 dB HL between 0.25 and 2 kHz. Figure 1 plots the average audiograms for younger and older adults. The threshold levels of older adults are no more than 12 dB higher than those of younger adults for frequencies 2 kHz. Beyond 3 kHz, hearing loss in older adults increased with frequency, indicating that they were in the early stages of presbycusis.

### 2.2 Stimuli and Apparatus

Stimuli were generated digitally with a sampling rate of 20 kHz and converted to analog form using a 16-bit Tucker Davis Technology (TDT) digital-to-analog converter.

The 2 kHz tone was gated on and off by multiplying it by an envelope constructed by summing a series of Gaussian functions (standard deviation ½ ms), spaced ½ ms apart (see Figures 2A, 2B, and 2C). As Figure 2 shows, the sum of a series of Gaussians forms a flat top envelop with ogival rise and decay times. The duration of the stimulus was defined as the time between the centers of the first and last Gaussian envelopes comprising the sum. For durations greater than 1.5 ms, the centers of the first and last Gaussians in the series correspond to the ½ power points of the envelope. Hence stimulus duration is the interval between the ½ power points.

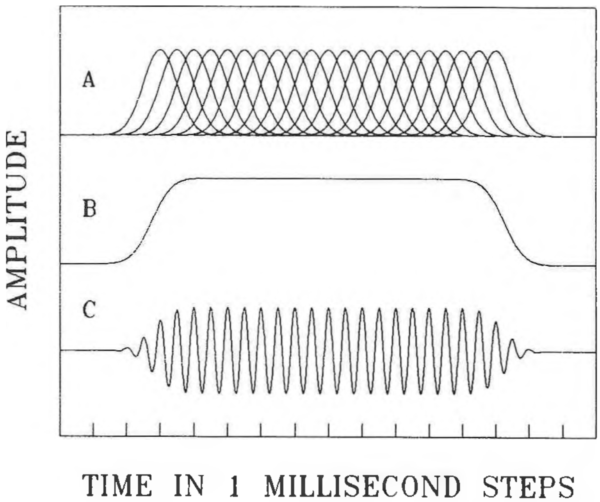


**Figure 2. The 21 Gaussian envelopes (s.d. = ½ ms) in panel A are added together to define the envelope in panel B. This envelope is multiplied by 2-kHz tone to produce the tone shown in panel C. The ½ power points on the envelope correspond to the peaks of the first and last Gaussian envelopes in panel A. Therefore the duration of the stimulus (time between ½ power points) is specified by the time between the peaks (10 ms) of the first and last Gaussians in the envelope.**

For stimuli 400 ms and longer, the sound pressure level of the stimulus during its steady-state portion was 66.5 dB SPL. For stimuli shorter than 400 ms, the total energy in the stimulus was set equal to the total energy in the 66.5 dB SPL, 400-ms tone. Thus, stimuli less that 400 ms in duration were equated for energy, stimuli longer than 400 ms were equated for sound pressure level. Short duration stimuli were equated for total energy because of the intensity-time tradeoff, and to minimize spectral differences between tones of different durations. The standard tone durations, the starting comparison tone duration for each standard tone, and the length of the unit steps separating successive comparison tones are all listed in Table 2. The starting comparison tone durations were selected after pilot testing several young and old adults on the procedure. Stimuli were presented to the left ear over TDH-49 earphones in a single-wall sound-attenuating booth.

### 2.3 Procedure

Duration discrimination thresholds were determined by presenting stimuli at each standard tone duration in a 2IFC paradigm. A staircase procedure was used to determine the 79.7% point on the psychometric function (Levitt, 1971). At the beginning of a block, a standard tone duration was chosen and the comparison tone duration was set to the value listed in Table 2. The standard and comparison tones were randomly assigned to the two intervals. After each trial was initiated by pressing a button, the two tones would occur, separated by a 100 ms silent period. Participants were asked

| Standard tone duration (ms) | Starting comparison tone duration (ms) | Unit step length (ms) |
|---|---|---|
| 1.5 | 72.0 | 0.5 |
| 5.0 | 99.5 | 0.5 |
| 10.0 | 72.0 | 0.5 |
| 20.0 | 89.0 | 1.0 |
| 40.0 | 182.0 | 2.0 |
| 80.0 | 204.0 | 4.0 |
| 200.0 | 500.0 | 5.0 |
| 400.0 | 1000.0 | 10.0 |
| 1000.0 | 2000.0 | 10.0 |

**Table 2. Durations of standard and comparison tone stimuli and unit steps in the staircase procedure.**

to choose which interval they thought contained the longer tone by pressing one of two buttons that corresponded to the two intervals. Lights on the response box indicated the beginning of the trial and whether the participants' response had been correct. The duration of the comparison tone was adjusted trial-by-trial according to a 3 down, 1 up rule. That is, if participants successfully discriminated between the two tone durations 3 times in succession, the next comparison tone duration would be decreased (closer in duration to the standard tone). However, if the participant responded incorrectly the comparison tone duration would be increased. Each block was terminated after 12 reversals; duration discrimination thresholds were defined as the mean of the last 8 reversals.

The order of standard tone durations was randomly assigned to each participant. Although all participants completed this procedure four times (four 1- to 1.5-hour sessions were required per participant), the first runs at all standard tone durations were treated as practice sessions and were not included in subsequent analyses; only the last three runs were used for the final threshold estimate.

## 3.0 RESULTS

Figure 3 plots the mean threshold duration increment (t) as a function of the duration of the 2-kHz standard tone in log-log coordinates for younger (circles) and older (squares) adults. Also shown are mean threshold values as a function of the duration of a 1 kHz tone for the two observers from Abel's (1972) experiment (triangles). The straight lines fit to the data from both of these experiments have identical slopes

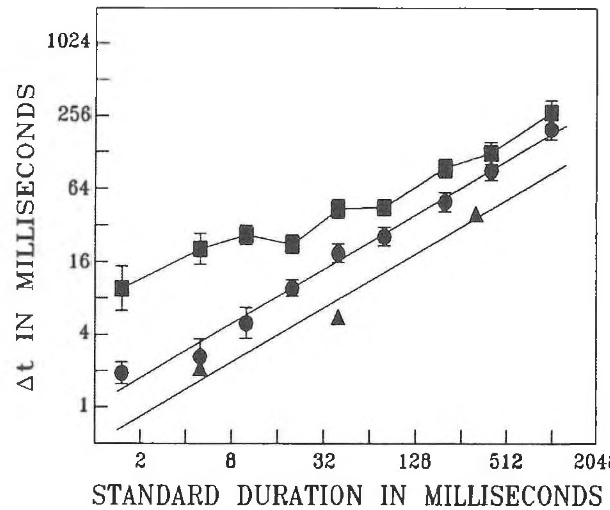


**Figure 3. Average threshold duration increment (Δt) (geometric mean) and standard errors as a function of the duration of the standard stimulus for younger (circles) and older (squares) adults. Also shown are the average data from Abel (1972).**

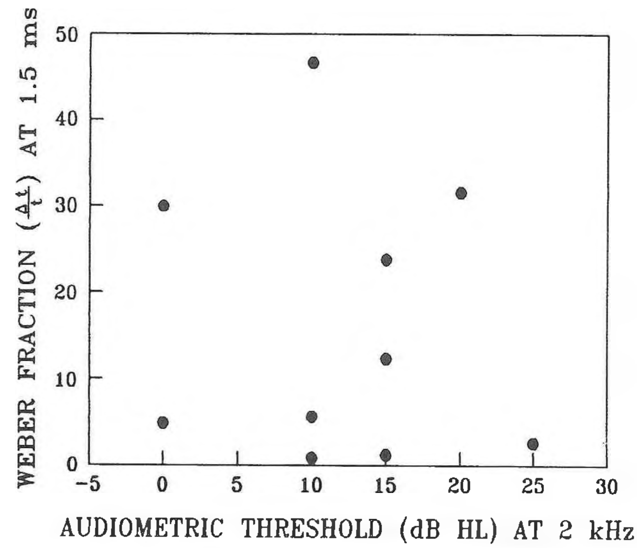


**Figure 5. Scatterplot of older adults' duration discrimination Weber fractions at the 1.5 ms standard tone duration and older adults' audiometric thresholds at 2 kHz.**

(0.74) but different intercepts. This means that for both sets of younger adults, t is a power function of duration with an exponent equal to 0.74; however, Abel's participants were more sensitive to changes in duration than the younger adults in the current experiment.[1]

At short durations, older adults have t values that are considerably higher than those of younger adults. However, at the longer durations, the two functions tend to converge. Figure 4 shows how relative sensitivity (the Weber fraction, t/t) varies as a function of standard duration. Relative sensitivity for older adults at the shortest duration (1.5 ms) was,

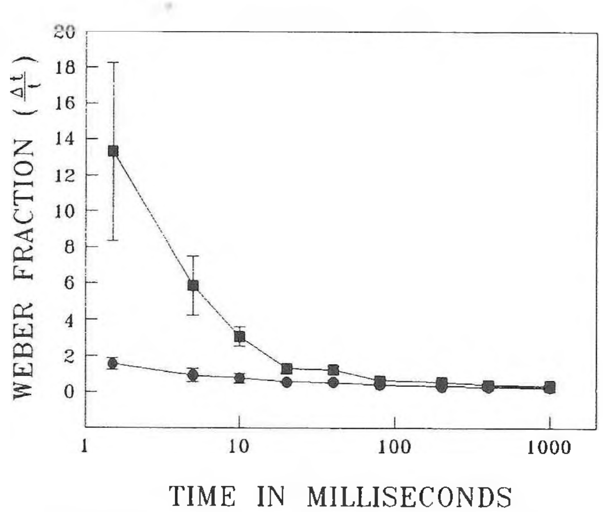


**Figure 4. Average (arithmetic mean) younger (circles) and older (squares) adults' duration discrimination Weber fractions and standard errors as a function of standard tone duration.**

on average, almost 7 times greater than for younger adults, compared to just 2 times greater at the 20 ms standard tone duration. This larger difference between younger and older adults' duration discrimination abilities at the 1.5 ms standard tone duration is also much larger than those performance differences found in previous duration discrimination studies (e.g., Abel et al., 1990; Fitzgibbons & Gordon-Salant, 1994; 1995).

To ensure that the variability in the older adults' performance at the shortest duration could not be explained by their audiometric thresholds, we compared the older listeners' Weber fractions at the 1.5 ms standard tone duration to their audiometric thresholds at 2 kHz. The scatterplot in Figure 5 reveals that the duration discrimination difficulties of older adults with relatively good hearing are not related to their audiometric thresholds.. In fact, younger and older adults' Weber fractions were not significantly correlated with audiometric threshold at 2 kHz at any of the standard tone durations (see Table 3). It is also important to note that not all older adults differed from younger adults, as can be seen by the data points near the abscissa in Figure 5.

## 4.0 DISCUSSION

Duration discrimination is much more difficult for older

[1] **Foot note:** The two participants in Abel's study were experienced observers, and had mean duration- discrimination thresholds that were lower than our mean thresholds. However, duration- discrimination thresholds for some of our young adults were as low or lower than those of Abel's observers.

| Standard Tone Duration | Younger Adults | Older Adults |
|---|---|---|
| 1.5 ms | 0.217 | 0.178 |
| 5 ms | -0.248 | 0.039 |
| 10 ms | -0.182 | -0.101 |
| 20 ms | 0.068 | -0.129 |
| 40 ms | -0.017 | -0.032 |
| 80 ms | -0.428 | 0.344 |
| 200 ms | -0.189 | 0.223 |
| 400 ms | 0.079 | -0.045 |
| 1000 ms | 0.304 | -0.396 |

Note: None of the correlations are significant at $p < .05$.

**Table 3. Correlation between standard tone duration and audiometric threshold at 2 kHz.**

listeners than for younger listeners at very short standard tone durations, but becomes easier at longer standard tone durations, where the performance of older and younger listeners is nearly identical. Younger listeners' duration discrimination performance also improves with increasing standard tone duration, but the slope is not nearly as steep as that of older listeners. The differential results for older and younger listeners are independent of audiometric thresholds, as expected from similar results reported in most duration discrimination experiments. That is, age-related changes in hearing threshold level most likely have no systematic effect on duration discrimination for older adults with relatively good hearing. Although the independence of duration discrimination and hearing thresholds is consistent with the suggestion of other researchers (e.g., Fitzgibbons & Gordon-Salant, 1996) that older adults' duration discrimination deficits reflect central rather than peripheral auditory dysfunction, the contribution of peripheral factors to these deficits cannot be ruled out. For example, age-related losses in the precision of temporal coding in the auditory nerve could lead to poorer duration discrimination. Thus, the results reported here cannot discriminate between losses in precision of temporal coding in the auditory periphery, and losses occurring more centrally.

It is important to note that performance variability decreased with increasing standard tone duration, especially for the older adults. That is, performance variability was quite large at the shortest standard tone durations. In fact, some of the older adults' duration discrimination abilities did not differ from those of the younger adults for brief stimuli, similar to the results of Fitzgibbons and Gordon-Salant (1994).

Another important issue is whether the listeners were responding to temporal differences rather than to spectral differences between stimuli at the shorter stimulus durations. However, an examination of the spectral differences between different short-duration stimuli indicate that it is unlikely that younger adults were discriminating on the basis of spectral differences. Figure 6 shows that the spectral density functions for a 5 ms and a 10 ms tone are quite comparable. In general, the envelopes of the spectral density functions for short- duration stimuli are quite similar. However, with

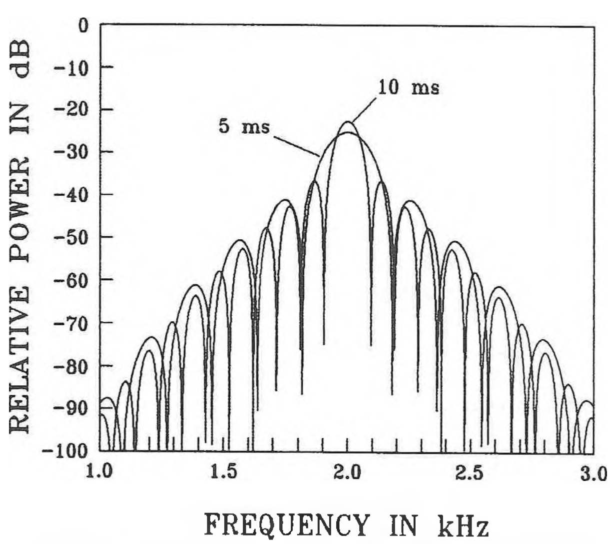


**Figure 6. Relative power spectral density functions for tones of 5 and 10 ms duration. Each tone was first normalized to have unit energy.**

| Duration of Standard | Weber Fraction<br>Younger Adults | Older Adults |
|---|---|---|
| 20 ms (500 Hz) | 0.8 | 1.8 |
| 20 ms (4000 Hz) | 0.6 | 1.3 |
| 20 ms (2000 Hz)* | 0.6 | 1.3 |
| 200 ms (500 Hz) | 0.3 | 0.4 |
| 200 ms (4000 Hz) | 0.2 | 0.4 |
| 200 ms (2000 Hz)* | 0.3 | 0.6 |

* Present experiment
Abel et al. (1990)

**Table 4. Comparison of duration discrimination Weber fractions for younger and older adults at standard stimulus durations of 20 ms and 200 ms.**

increasing duration, the width of the center and side bands decreases while the number of sidebands increases. Because of the overlap in these distributions it is more likely that the discriminability of these two stimuli is based on their duration difference (5 vs 10 ms) than on their spectral differences.

The pattern of results from the present experiment is consistent with several previous studies. First of all, Small and Campbell (1962) found that young adults' temporal discrimination ability diminished as standard duration decreased from 400 ms to 0.4 ms. Furthermore, Getty (1975) investigated two highly practiced listeners' duration discrimination for empty auditory intervals ranging from 50 ms to 3200 ms and also found that the Weber fraction function dropped over the shorter standard durations and then flattened out up to 2000 ms. Finally, the results of younger and older listeners at standard tone durations of 20 ms and 200 ms in the present experiment are quite similar to the duration discrimination Weber fractions of Abel et al. (1990) at the same durations, as shown in Table 4.

These results have implications for older listeners' understanding of speech, especially speeded speech or speech in noise. Considering that critical phonemic information in speech often occurs at durations much shorter than 20 ms, older adults would have a very difficult time utilizing such cues to decipher particular words in the speech stream, especially in noisy situations. In addition, Peterson and Lehiste (1960) have shown that, in English, the duration of a vowel is influenced by the preceding or following consonant. For example, the vowel duration in the word "rice" is much shorter than vowel duration in the word "rise." Hence, vowel duration can serve as an additional cue to word identification in noisy situations where the consonants may be partially or completely masked. Older adults would be disadvantaged in such situations if they could not easily discriminate differences in vowel duration.

Some studies of older adults' temporal processing have supported this idea. For example, Lutman (1991) found that older adults with extremely poor gap detection thresholds also tended to have diminished speech identification scores. Furthermore, Gordon-Salant and Fitzgibbons (1993) found that gap duration discrimination is related to older adults' ability to recognize reverberant speech, as mentioned earlier. However, they did not find strong correlations between duration discrimination and understanding of temporally distorted speech. Similarly, Abel et al. (1990) did not find that duration discrimination was a factor in the intelligibility of speech.

In conclusion, the present study demonstrates that older adults perform more poorly than younger adults at duration discrimination for short duration stimuli, but older and younger adults perform similarly at longer duration stimuli. This diminished temporal processing capability in older adults could make it more difficult for them to process speech in difficult listening situations where there is noise, reverberation, or when speech is speeded.

## 5.0 AUTHOR'S NOTE

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