

4-9-2004

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Effects of age and stimulus frequency on gap discrimination

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April 9, 2004

Tampa, Florida

Keywords: Temporal Resolution, Age, Frequency Region, Frequency Disparity

Abstract

Objective: Deficits in temporal resolution may be one element underlying the speech understanding difficulties experienced by older listeners in degraded acoustic environments. In real listening environments, important temporal cues are surrounded by stimuli of varying frequencies. This study was designed to assess temporal resolution as a function of frequency region, frequency-disparity, and age in listeners with normal hearing.

Design: Gap duration difference limens (GDDLs) were measured using leading and trailing markers that were fixed at the same frequency (fixed-frequency) or at frequencies one-half octave apart (frequency-disparate) for two groups of listeners with normal hearing: (1) 18-22 years and (2) 55-66 years. Two distinct frequency regions were represented, 500 Hz and 4000 Hz.

Results: The results indicated significant effects of age, frequency region, and frequency disparity on GDDLs. Poorer overall performance was observed for the older listeners, the lower frequency region, and the frequency-disparate condition.

Conclusions: Gap discrimination is negatively affected by advanced age, lower marker frequencies, and larger marker frequency disparities.

INTRODUCTION

Many auditory perceptual abilities decline with increasing age and hearing loss, (Willott, 1991). Most critical is that listeners with presbycusis have difficulty understanding speech, particularly when that speech is presented in reverberation and noise (e.g., Koehnke & Besing, 1996; Kramer et al., 1998; Nabelek & Mason, 1981). One factor known to be essential to speech perception in such everyday environments is temporal resolution (i.e., the ability to follow rapid temporal fluctuations and integrate acoustic stimuli over time). Often, the background noise found in everyday listening situations is characterized by fluctuations in intensity over time. It has been suggested that temporal resolution enables a listener to use brief dips in the intensity of interfering noise to understand speech in these situations (Dubno et al., 2003; Oxenham, 2002; Peters et al., 1998). In fact, several studies have shown links between temporal resolution and the understanding of acoustically degraded speech (Gordon-Salant & Fitzgibbons, 1993; Irwin & McAuley, 1987; Snell et al., 2002; Tyler et al., 1982).

Recent literature describes two primary measures of temporal resolution: (1) gap detection, a measure of temporal acuity typically described as a gap detection threshold (GDT) and (2) gap discrimination, a measure of temporal discrimination described here as a gap duration difference limen (GDDL). A GDT is a traditional measure representing the smallest silent interval in a stimulus that a listener can detect, and GDDL represents the smallest change in the duration of a silent interval that a listener can discriminate. In the traditional GDT task, the standard interval consists of a continuous signal or two contiguous signals, and the target interval consists of a signal interrupted by a silent temporal gap of varying duration. Divenyi and Danner (1977) hypothesized that this type

of temporal task may rely on detection of gating transients that are present in the target interval and absent in the standard interval. Therefore, an advantage of using discrimination tasks to measure temporal resolution is that similar gating transients are present in all stimuli (i.e., all stimulus choices are interrupted by a silent gap, one of which is longer than the others).

Studies of gap discrimination and gap detection suggest that reduced temporal resolution in older listeners may occur independently of peripheral hearing loss (Fitzgibbons & Gordon-Salant, 1994; Grose et al., 2001; Lister et al., 2000; Roberts & Lister, 2004). This effect is often attributed to age-related changes within the central auditory system and slowed auditory processing (Fitzgibbons & Gordon-Salant, 1994; Gordon-Salant & Fitzgibbons, 1999; Salthouse, 1985). Fitzgibbons and Gordon-Salant (1994) measured gap discrimination using fixed-frequency and frequency-disparate tone burst markers centered at 500 and 4000 Hz for four groups of listeners (young/older, with/without hearing loss). Gap discrimination was poorer for the older listeners and for the frequency-disparate markers. The differences between age groups were larger for the frequency-disparate markers than for the fixed-frequency markers. However, no effect of frequency region was observed.

Some evidence also exists for hearing-loss related deficits in temporal resolution (Fitzgibbons & Wightman, 1982; Florentine & Buus, 1984; Glasberg et al., 1987; Grose & Hall, 1996; Tyler et al., 1982). Tyler et al. (1982) measured gap detection and gap discrimination in listeners with and without hearing loss using 500 and 4000 Hz noise burst markers. Listeners with hearing loss showed significantly poorer performance than listeners with normal hearing. Performance was significantly better for the higher

frequency (4000 Hz) stimuli than for the lower frequency (500 Hz) stimuli, across groups. Because the listeners with hearing loss (mean age = 53) were older than the listeners with normal hearing (mean age = 23), the results were confounded by listener age. Studies showing normal gap resolution by listeners with sensorineural hearing loss (Grose et al., 2001; Lister et al., 2000) and impaired gap resolution by listeners with normal hearing (Fitzgibbons & Gordon-Salant, 1994; Lister et al., 2002) seem to suggest that hearing sensitivity alone does not determine temporal resolution. In addition, the effects of hearing loss may be confounded somewhat by the effects of stimulus frequency region on temporal resolution.

Snell et al. (1994) suggested that a region of dominant temporal sensitivity exists around 4 kHz. Others have also suggested that gap detection for broad-band stimuli is influenced by the high-frequency components of the stimulus (Fitzgibbons, 1983; Formby & Muir, 1988; Snell et al., 1994). As older listeners often have reduced hearing sensitivity in this frequency range, it is possible that reduced high frequency hearing contributes to poor temporal resolution. Other literature (Fitzgibbons & Gordon-Salant, 1987) suggests that as long as the markers are presented at 25-30 dB sensation level, gap perception across frequency should be optimal.

Resolution of silent gaps is also highly dependent upon the frequency disparity of the signals (markers) that bound the gap, a dependence that has been explained using the perceptual channel hypothesis (Formby et al., 1998; Grose et al., 2001; Oxenham, 2000; Phillips et al., 1997). According to this hypothesis, the discrimination of gaps between markers differing in frequency by more than half an octave requires across-channel processing, for example, across two or more perceptual channels. The

discrimination of gaps between markers that are close in frequency (less than half an octave apart) utilizes within-channel processing, for example, within a single perceptual channel. For across-channel processing, the listener must discriminate a gap that exists between the offset of a marker in one channel and the onset of a marker in another channel. In the within-channel case, the listener need only monitor the activity in a single channel. Experimental results obtained for listeners with normal and impaired hearing support this hypothesis; measures requiring within-channel processing result in better gap detection and gap discrimination than those that require across-channel processing (*Lister et al., 2002; Roberts & Lister, 2004*). Within-channel and across-channel gap detection and discrimination has been widely used to document age- and hearing loss-related deficits of temporal resolution (*Lister et al., 2002; Moore et al., 1992; Schneider et al., 1994; Snell, 1997; Strouse et al., 1998*).

The purpose of this study was to assess temporal resolution using a gap discrimination task in two age-groups of listeners with normal hearing, one younger and one older. Silent gap discrimination was measured using markers of the same frequency (fixed-frequency) and markers that differed in frequency before and after the gap (frequency-disparate). In addition, gap discrimination was measured in two frequency regions: 500 Hz and 4000 Hz.

Specifically, we hypothesized that: 1) Older listeners would have poorer overall GDDLs than younger listeners; 2) GDDLs for frequency-disparate markers would be poorer than GDDLs for fixed-frequency markers; 3) GDDLs for higher frequency markers (4000 Hz) would be better than GDDLs for lower frequency markers (500 Hz);

and 4) The effects of frequency-disparity would be greater for older listeners than for young listeners with normal hearing.

METHOD

Participants

Two groups of listeners were recruited from current subject pools, from USF faculty, staff, and students, and from the Tampa Bay community: (1) 6 listeners aged 18-22 years (mean age = 20; s.d. = 1.41) with normal hearing (YNH) and (2) 6 listeners aged 55-66 years (mean age = 60; s.d. = 3.87) with normal hearing (ONH). Normal hearing was defined as pure-tone thresholds of 20 dB HL or better at frequencies from 250 through 8000 Hz in both ears. Each subject participated in two test sessions (1-2 hours each). Informed consent was requested and received from all listeners. Average and individual pure tone thresholds are presented in Table 1.

A three-way mixed analysis of variance (ANOVA) with one between-subjects factor (listener group) and two within-subjects factors (ear and frequency) revealed that the pure tone thresholds of the YNH listeners were significantly better than those of the ONH listeners $F(1,10)=32.49$, $p=0.0002$. The thresholds did not differ significantly across frequency $F(5,50)=0.186$, $p=0.966$ or between the two ears $F(1,10)=0.026$, $p=0.874$; therefore, pure tone thresholds presented in Table 1 are averaged across ear. It is noted that the thresholds of the ONH listeners are within the range of what is considered normal audiometric hearing sensitivity, especially given their ages (Brant & Fozard, 1990).

Table 1. Pure tone thresholds (dB HL) for individual older normal hearing (ONH) and mean thresholds for the young normal hearing (YNH) group are shown. Standard errors are shown in parentheses.

Group	Age	Pure Tone Thresholds (dB HL)					
		250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
YNH n = 6	20	2.9 (0.77)	4.2 (1.5)	5.4 (0.8)	5.0 (2.5)	2.1 (1.0)	3.8 (1.8)
ON1	59	20	10	5	10	15	15
ON2	62	15	10	20	15	15	15
ON3	55	10	20	20	10	20	20
ON4	66	15	20	10	15	20	20
ON5	57	10	20	5	5	0	0
ON6	61	10	15	10	10	5	20
ONH n = 6	60	13.8 (1.7)	13.8 (1.5)	12.1 (2.8)	13.3 (1.5)	13.8 (3.1)	15.0 (3.1)

Stimuli

Noise band stimuli (markers) for the gap discrimination tasks, were computer generated, 300 ms in duration, 1/4 octave wide, and geometrically centered on one of the 6 frequencies listed in Table 2.

Table 2. Gap Discrimination Frequency Conditions

Marker Frequency Condition	Center Frequency of Lead (Hz)	Center Frequency of Trail (Hz)	Disparity
Fixed-Frequency	4000	4000	None
Fixed-Frequency	500	500	None
Frequency-Disparate	421	595	1/2 octave
Frequency-Disparate	3364	4760	1/2 octave

The frequencies and durations were chosen to facilitate comparisons with the results of Tyler et al. (1982) and Fitzgibbons and Gordon-Salant (1994). All stimuli were presented at a fixed, audible level of 75 dB SPL.

Instrumentation

All noise band markers were generated digitally (20-kHz sampling rate) using a Tucker-Davis Technologies (TDT) Psychoacoustics System consisting of a 32-bit

digital-to-analog (D/A) converter, anti-aliasing filters (9-kHz cutoff), attenuators, a headphone buffer, and a laboratory computer. Stimulus presentation and recording of listener responses was controlled by locally developed software. All stimuli were presented binaurally via Sennheiser earphones. Listeners were tested individually in a sound treated room where they used a computer mouse to make selections on a computer screen relative to their perception of the auditory stimuli.

Procedures

A three-interval, three-alternative, forced-choice (3I/3AFC) procedure targeting 70.7% correct discrimination (Levitt, 1971) was employed to reduce cognitive task demands. In this type of task, listeners must only select the odd stimulus and detailed understanding of the stimulus parameters is not required. This procedure has been recommended (Leek, 2002) for investigations of the auditory perception of aged listeners. Prior to each temporal resolution measure, the listener was familiarized with the task and stimuli by listening passively to several trials. The noise band markers were paired so that the center frequency of the leading (before the gap) and trailing (after the gap) markers were fixed at the same frequency (fixed-frequency condition) or at frequencies $\frac{1}{2}$ octave apart (frequency-disparate condition) for each experimental run. The specific frequency combinations are detailed in Table 2. As a result, the presence/absence of frequency disparity was varied between runs and two distinct frequency regions were represented.

Each marker pair was separated by a silent temporal gap, and gap duration difference limens (GDDLs) were measured in random order for the four marker center-

frequency combinations (Table 2). The following instructions were given to each listener:

“Gap discrimination is a test that measures your ability to hear that one sound is the same or different from another. In this test, you will hear three noise bursts, two will be the same and one of them will be different from the other two. Your job is to pick the one that is different. Depending on your response, the anomalous or different burst may become easier to hear or totally undetectable to you. The computer program will automatically track your response and calculate the smallest difference that you can detect among the three tone bursts.”

The listener chose among two standard intervals in which the markers were separated by a standard gap (100-ms to facilitate comparison with previous studies) and one target interval in which the gap duration was varied adaptively. Presentation order of the standard and target intervals was randomized across trials. Additional experimental runs were completed if a listener demonstrated inconsistent performance. Within an experimental run, the marker center-frequency combination remained constant. Marker duration was varied within a range of 250 to 350 ms to control for extraneous marker duration cues that may aid gap discrimination. Three runs of each condition (four center-frequency combinations, four noise conditions) were completed for a total of 48 runs. Each run lasted 3-5 minutes; therefore, total data collection time was approximately 2.5-4 hours.

RESULTS

The effect of age and frequency region on gap discrimination was measured using fixed-frequency and frequency-disparate noise band markers. We hypothesized that GDDLs would be poorest for older listeners, lower frequency markers, and frequency disparate markers.

Figure 1 shows GDDLs for each group and frequency condition. As illustrated by the figure, the YNH listeners had smaller GDDLs than the ONH listeners. Group differences are more apparent for the fixed-frequency conditions than for the frequency-disparate conditions. Best overall performance was observed for the 4000 Hz fixed-frequency condition for both groups.

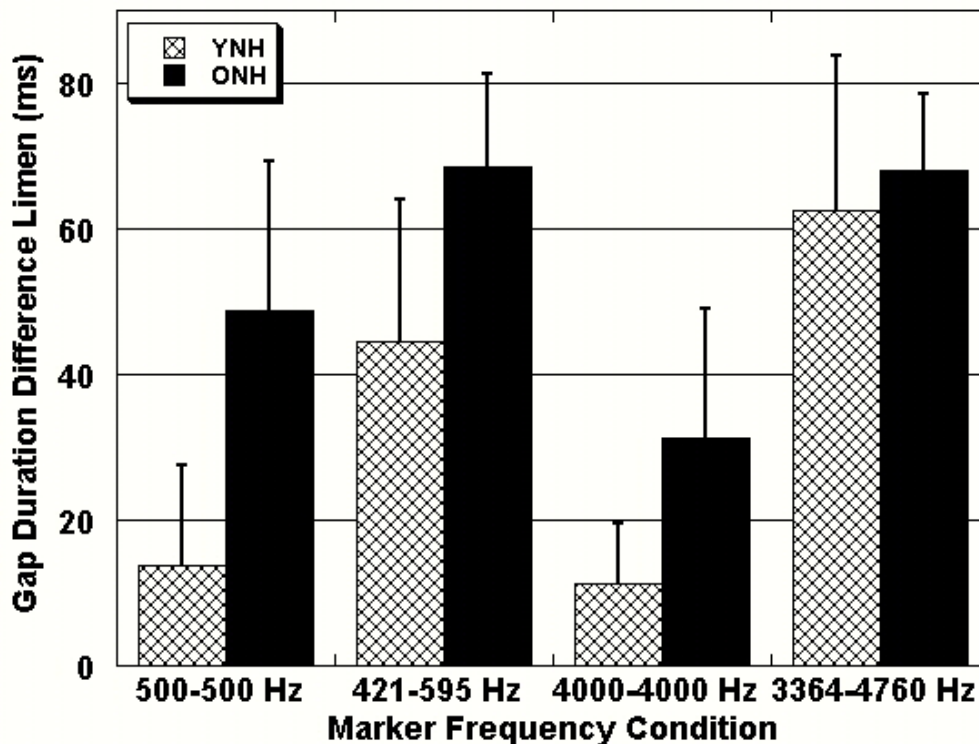


Figure 1. Average Gap Duration Difference Limens (GDDLs) for the two listener groups and the four frequency conditions. Hatched bars represent performance of the young listeners with normal hearing. Solid bars represent performance of the older listeners with normal hearing. Standard error bars are shown for group and frequency condition.

A three-way mixed ANOVA revealed that the effect of group [$F(1,10)=56.25$; $p=0.00002$] and the effect of frequency condition [$F(3,30)=101.36$; $p<0.00001$] were statistically significant as was the interaction between group and frequency condition [$F(3,30)=8.86$; $p=0.0002$]. Due to the presence of a significant interaction, the data for each group and frequency condition were compared using a one-way ANOVA. This

analysis indicated a significant difference between the means [$F(7,35)=63.62$, $p<0.00001$]. A Tukey HSD post-hoc analysis indicated that the YNH listeners had significantly lower GDDLs than the ONH listeners for all frequency conditions ($p<0.0007$) except the 3364-4760 Hz condition ($p=0.8784$). For the ONH listeners, significantly lower GDDLs were found for the high fixed-frequency condition (4000-4000 Hz) than for the low fixed-frequency condition (500-500 Hz) ($p=0.00329$) but no difference was found between the high and low frequency-disparate conditions ($p=0.99$) for this group. For the YNH listeners, the reverse was found. Their low and high frequency GDDLs differed significantly for the frequency-disparate condition ($p=0.0022$), but not for the fixed-frequency condition ($p=0.99$). When fixed-frequency and frequency-disparate conditions were compared for the same frequency region (i.e., 500-500 vs. 421-595 Hz and 4000-4000 vs. 3364-4760 Hz), significantly lower GDDLs were found for the fixed-frequency conditions for both listener groups ($p<0.0007$).

DISCUSSION

The purpose of this study was to investigate the effects of age and frequency on gap discrimination. The results indicated significant effects of age, frequency region, and frequency disparity on GDDLs. Older listeners had poorer overall average GDDLs than the younger listeners. As expected based upon the perceptual channel hypothesis (Formby et al., 1998; Grose et al., 2001; Oxenham, 2000; Phillips et al., 1997), resolution of silent gaps was highly dependent upon the characteristics of the signals (markers) that bound the gap. Both listener groups demonstrated poorer GDDLs in the frequency-disparate conditions as compared to the fixed-frequency conditions.

Based on the studies of Snell et al. (1994) and Tyler et al. (1982), GDDLs for high frequency markers (4000 Hz) were expected to be better than GDDLs for lower frequency markers (500 Hz). Overall lower GDDLs were measured for the 4000 Hz fixed-frequency condition than for the 500 Hz fixed-frequency condition.

Examination of the data for six hearing-impaired listeners aged 55-80 years from Tyler et al. (1982) revealed average GDDLs of 95.4 and 91.1 ms for the 500 and 4000 Hz markers, respectively. For their 16 young listeners with normal hearing, Tyler et al. measured average GDDLs of 75.7 and 71.2 ms for 500 and 4000 Hz markers. In the present study, we measured GDDLs of 13.7 and 11.4 ms for 500 and 4000 Hz for the YNH listeners. For the ONH listeners, we measured GDDLs of 48.7 and 31.4 ms, respectively. This discrepancy may be attributed to Tyler et al.'s use of 500 ms marker durations, double those used in the present study.

The effects of frequency condition were expected to be greater for the older listeners than for the younger listeners. Fitzgibbons and Gordon-Salant (1994) found larger age effects for frequency-disparate markers than for fixed-frequency markers using tone burst stimuli. In the present study, group differences were actually smaller for the frequency-disparate conditions than for the fixed-frequency conditions. A repeat testing of the subjects was planned to investigate the repeatability of this anomalous finding. However, we were unable to do so due to Institutional Review Board (IRB) regulations and time constraints. Further investigation into the matter using similar subjects is warranted due to the unusual findings.

In partial explanation of the anomalous findings, we offer several observations. The ONH listeners had normal hearing levels for 250 through 8000 Hz. The excellent

pure tone thresholds of the ONH group may have contributed to the differences found in the present study compared to results of previous research. Also, the ONH listeners were of excellent physical health. *There are still many theories addressing the question of the aging auditory system's inability to understand speech clearly. Research has pointed to a decline in perception of brief acoustic cues, age related decline in temporal processing ability in general, and the age related changes in auditory processing. Each of these could contain a possible explanation by itself; however it is often an interaction of these proposed theories that has an effect on an aging auditory system, and more research is called for to narrow the varied possibilities. The continuing research should utilize older listeners with excellent pure tone thresholds and a history of a healthy lifestyle.*

CONCLUSION

The results of this study indicate that age and marker frequency composition negatively affect gap discrimination. This effect may influence the speech perception difficulties so often experienced by older listeners in noisy environments. Temporal cues that occur between spectrally dynamic, low frequency stimuli may be particularly difficult for older listeners to perceive.

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