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Case Study

# Auditory temporal resolution remains intact in low-frequency hearing loss: A case study

## Abstract

**Objective:** To explore the hypothesis that a low-frequency hearing loss would not significantly impair an individual's auditory temporal resolution performance.

**Background:** Listeners with high-frequency sensorineural hearing loss demonstrate poorer temporal resolution performance. This detriment has been attributed to the absence of high-frequency hearing. It is believed that functional hearing in these individuals is restricted to low-frequency auditory channels where temporal resolution, albeit normal, is characteristically poorer to that of the high-frequency channels. From this, one could hypothesize that a low-frequency hearing loss would not impair an individual's temporal resolution if high-frequency auditory channels remain intact.

**Methods:** A patient with a unilateral rising low-frequency hearing loss underwent a battery of temporal resolution tasks (i.e., recognition of time compressed and reverberated words and words in interrupted noise). Performance differences between the two ears of the adult were compared to each other and to normal controls.

**Results:** No statistically significant differences in word recognition performance in quiet or in time compression, reverberation, and noise were observed between the normal and impaired ear. There was also no difference between the impaired ear and that of normal-hearing controls.

**Conclusion:** These findings support the hypothesis that a restrictive listening bandwidth impairs temporal resolution only when high-frequency channels are lost.

## Case Study

Temporal resolution/acuity and temporal integration/summation are two forms of temporal processing of the auditory system [1]. Temporal resolution is the ability of a listener to discern auditory events and/or to recognize alterations in auditory events across time. Temporal integration refers to a listener's capacity to integrate acoustic information to facilitate detection, recognition, and/or discrimination across time. One means of demonstrating temporal resolution ability is to have listeners identify speech in competing "time-varying" maskers. When maskers are time-varied; listeners experience a perceptual benefit or a "release from masking." That is, speech recognition in these maskers expose an individual's temporal resolving capacity to get "glimpses" or "looks" of speech in the gaps or modulations of noise and to piece the signal together for speech identification [2-4]. Listeners with sensorineural hearing loss, however, show diminished release from masking compared to normal hearing individuals in competing interrupted broadband noise [5-12] and time-varying maskers of interrupted speech babble [13] and amplitude modulated noise [14-20].

Poorer performance of listeners with sensorineural hearing loss in time-varying maskers has been attributed to impaired high-frequency auditory channels, which has at least two broad consequences: The first is stimuli presentation at a reduced level. This results in stronger temporal masking as forward masking recovery depends on the sensory response evoked by the masking stimulus. Sluggish recovery from temporal masking in the time-varying is found in, hearing -impaired individuals relative to normal-hearing listeners [21,22]. The second consequence is reduced peripheral listening bandwidth. There are two means of looking at available listening bandwidth limiting temporal resolution [11,23]. One is spectral. Listeners with hearing impairment are characterized with cochlear auditory filters in the impaired region that are broadened and insensitive and consequently more vulnerable to competing noise [1]. In addition, performance is hindered



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when part or all of the signal is inaudible [24-26]. A number of investigators have proposed, however, that audibility is not solely responsible for diminished release in masking with hearing-impaired listeners [14-17,27-28]. It has also been proposed that a bandwidth with reduced high-frequency audibility limits performance *also* in the temporal realm. That is, hearing-impaired individuals are at a disadvantage when it comes to temporal processing owing to a loss of functioning high-frequency peripheral auditory channels [23,25,29-31]. It is believed that hearing in these individuals is limited to low-frequency auditory channels where temporal resolution albeit normal is characteristically poorer relative to high-frequency auditory channels. As a consequence performance on temporal resolution tasks is diminished in individuals with high-frequency hearing loss relative to normal-hearing individuals.

One way of showing the influence of restricted listening bandwidth on temporal resolving ability is to contrast listeners with simulated high-frequency impairment versus without. For example, Stuart, Phillips, and Green [32], mimicked a high-frequency hearing impairment with low-pass filtering (i.e., at 2000 Hz with a roll-off slope of 48 dB/octave) words in backgrounds of continuous and interrupted noise with varying signal-to-noise ratios (S/Ns) in normal-hearing adult listeners. In competing continuous noise, performance was equal with and without the simulated high-frequency loss. In competing interrupted noise, performance was significantly poorer in the interrupted noise with the simulated hearing loss when compared to their performance without the simulated hearing loss. Stuart et al,. [32], argued the listener's performance in both noises during simulated high-frequency loss could not be justified by loss of signal audibility only. To wit, loss of high-frequency auditory channels selectively impaired listeners in the interrupted noise only, a condition tasking temporal resolution.

Scott, Green, and Stuart [33], also mimicked high-frequency hearing loss and examined word recognition in continuous and interrupted noises while S/N varied. Words were low-pass filtered (i.e., cutoff frequencies of 1000Hz, 1250Hz and 1500Hz) and presented in competing continuous and interrupted noise at three S/Ns (i.e., -10, 0, +10dB). Two main findings were evident. First, word recognition performance improved with increasing low-pass cutoff frequency for both noises as expected due to the gain of spectral information with decreased filtering. More important, in the interrupted versus continuous noise, was an increase in the release from masking. That is, an advantage in the interrupted noise condition, relative to the continuous condition at equivalent S/Ns, was more with increasing low-pass cutoff frequency. In other words, as listening was progressively increased to the higher frequencies the perceptual advantage due to the temporal release of masking improved.

Elangovan and Stuart [34], demonstrated the performance superiority observed in the interrupted versus continuous noise did not diminish with high-pass filtering simulating low-frequency hearing loss (i.e., release from masking in interrupted noise remained intact). They examined high-pass filtering at three different cutoff frequencies (i.e., 1000, 1250 and 1500 Hz) to simulate low-frequency hearing impairment. Overall performance diminished in both noises with increasing restrictive filtering attributed to decreased audibility. However, the release of masking in the interrupted noise was preserved with high-pass filtering. They reported an average word recognition performance advantage of approximately 35% to 40% at -10 S/N, and 35% at 0 S/N in the interrupted noise conditions over the continuous noise conditions, regardless of high-pass filter cutoff. They concluded that losing low-frequency auditory channels *does not* significantly impair temporal resolution abilities.

The hypothesis, that impairment of low-frequency auditory channel functioning does not significantly weaken temporal resolution, was explored in this study with an adult with a unilateral low-frequency hearing loss. It was maintained that performance on tasks of temporal resolution among hearing impaired listeners is not only governed by restrictive listening bandwidth but also where that loss of restrictive listening bandwidth is located. With a high-frequency hearing loss, temporal resolution task performance is hampered by the loss of audibility *and* a loss in temporal resolution from absent high-frequency auditory channels that have the best temporal resolution. Further, with a low-frequency hearing loss, the deficit of low-frequency channels should not significantly hinder an individual's temporal resolution if undamaged high-frequency channels remain. Performance differences between the two ears of the adult with the unilateral low-frequency hearing loss were compared to each other and normal-hearing controls on three temporal resolution tasks. It was hypothesized that there should be no difference between the two ears neither of the adult participant nor with the control group of normal-hearing listeners.

## Method

### Patient

A 23-year-old adult female was referred to the East Carolina University Speech Language and Hearing Clinic at for a suspected hearing loss on the left side following a failed hearing screening. Over two appointments she received a complete audiologic workup to rule out retrocochlear pathology. Her history was unremarkable with the exception noise exposure from loud music concerts, occasional tinnitus following such, and both maternal and paternal grandfathers presenting with amplification use following adult acquire hearing loss (i.e., presbyacusis). She reported no complaints of listening difficulty.

### Audiometric workup

The test environment was a double wall sound-treated audiometric suite. The patient presented with normal hearing sensitivity on the right side defined as having pure-tone thresholds at octave and inter-octave frequencies from 250 to 8000 Hz of ≤ 20 dB HL. Figure 1 illustrates her audiogram. Spondee recognition thresholds (SRTs) were consistent with three-frequency pure tone averages in the right and left ears (cf. 8 and 23 vs. 8.3 and 26.6, respectively). Word recognition was excellent in the right (98%) and left ear (96%).



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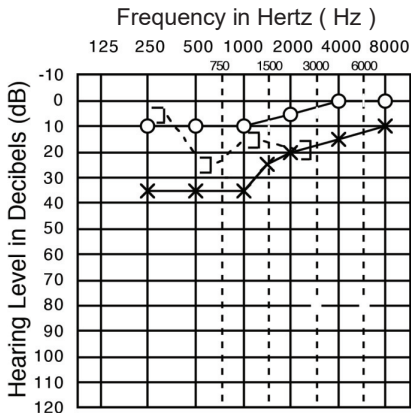


**Figure 1:** The patient's audiogram.

Otoscopy was unremarkable bilaterally. Tympanometry indices of static admittance, tympanometric width, and equivalent ear canal volume were normal bilaterally [35]. Acoustic reflexes were present in the right ear and absent in the left with ipsilateral presentation of puretone stimuli from 500 Hz to 4000 Hz in octave steps. Contralateral acoustic reflexes were absent with stimulation on the left side with pure tone activator stimuli of 500 and 1000 and elevated at 2000 and 4000 Hz. Contralateral acoustic reflexes on the right side were present with pure tone activator stimuli of 500, 1000, 2000 and 4000 Hz. Tone decay tests [36], were negative bilaterally with 500, 1000, and 2000 Hz pure tone stimuli. Absolute and interpeak auditory brainstem response wave latencies were within acceptable clinical normative data bilaterally with click stimuli presented at 90 dB nHL at rates of 7.7 and 77.7/s. Wave V/I amplitude ratios were within acceptable limits bilaterally also. Interaural latency differences were minimal. Annual hearing assessment and hearing conservation was recommended to the patient.

Following the audiometric workup, the patient was also referred to an ear, nose, and throat physician considering the previously undiagnosed unilateral hearing loss and unexplained air-bone gap on the left side at 250 Hz. The physician reported normal findings but did recommend a limited magnetic resonance imaging study as a further precaution to rule out retrocochlear pathology on the left side. The patient was noncompliant with this recommendation and chose annual hearing assessment.

### Auditory temporal resolution assessment

Auditory temporal resolution capacity was assessed with a battery of word recognition tests. It included word recognition in noise (continuous and interrupted) and word recognition with temporal distortions (i.e., time compression and reverberation). Test stimuli were played from a compact disc player (JVC Model XL-FZ258) via a clinical audiometer (Grason Stadler GSI 61 Model 1761-9780XXE) and insert earphones (Etymotic Research Model ER-3A).

Stimuli were presented monaurally at 30 dB SL re the patient's SRTs.

Compact disc recordings of 50 monosyllabic word lists of the Northwestern University Auditory Test No. 6 (NU-6) served as the test stimuli. Compressed 45% and 65% NU-6 stimuli were obtained from the *Tonal and Speech Materials for Auditory Perceptual Assessment, Disc* 2.0 compact disc [37]. Uncompressed NU-6 stimuli were obtained from the *Speech Recognition and Identification Materials, Disc 1.1* compact disc [38]. The recorded stimuli were routed from the compact disc player through a multi-effect digital signal processor (DigiTech Model Studio 400) to create reverberant listening. Reverberation times were 1.75 and 2.25 s. Custom-made compact disc recordings of the NU-6 stimuli and competing noises were used to assess word recognition in competing noises at seven S/Ns [11,39]. Testing of ears and word recognition conditions were counterbalanced. S/N was counter balanced with a digram-balanced design [40], while NU-6 lists were Latin square design counterbalanced.

## Results

The patient's word recognition scores in noise are presented and those for time compression and reverberation are found in Figures 2 and 3, respectively. Two standard deviations (plus/minus) from the mean from a normative adult normal-hearing group ($n$ = 12) are depicted with broken lines. Recall from above and plotted in Figure 3 are excellent word recognition performance (i.e., 98% and 96% for the right and left ear, respectively) in quiet (0.0s reverberation and 0% time compression). As expected, performance was superior in the interrupted noise, performance decreased with poorer S/N, and

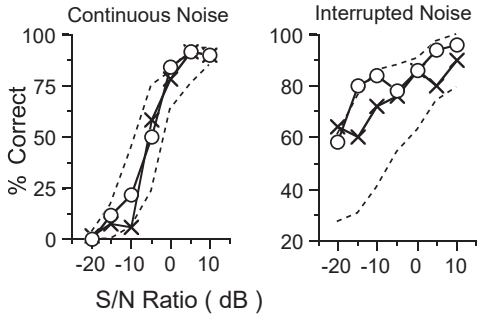


**Figure 2:** Continuous and interrupted noise word recognition performance as a function of signal-to-noise ratio. Right and left ears are represented by circles and crosses, respectively. Plus/minus two standard deviations from the mean from a normative normal-hearing group (n = 12) are displayed with broken lines.

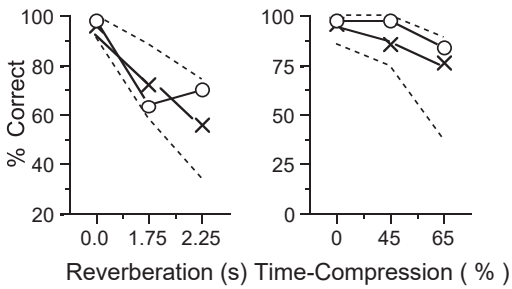


**Figure 3:** Reverberation and time compression word recognition performance as a function of time (s) and percent compression (%). Right and left ears are represented by circles and crosses, respectively. Plus/minus two standard deviations from the mean from a normative normalhearing group ($n$ = 12) are displayed with broken lines.



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performance decreased with increasing reverberation and time compression. Performance was essentially within normal limits bilaterally. Most important is the observation that performance between ears is essentially equivalent.

To assess statistically if differences between ears existed, critical differences were examined and applied for right and left ear comparisons [41,42]. A Bonferroni correction was undertaken to maintain a type I family-wise error of .05. A per comparison significance level of $\alpha = .002$ was therefore adopted. There were no significant differences ($p > 0.002$) found in 19 comparisons between ears (i.e., one in quiet; two each in reverberation and time compression; and seven each in continuous and interrupted noise).

## Discussion

The performance of this listener with unilateral hearing impairment was consistent with normal-hearing adult controls. This was true regardless of ear (i.e., normal or impaired) and whether word recognition performance was in quiet, noise, or with temporal alterations of time compression and reverberation. It is argued that findings of this study and those from previous work support the notion that a restrictive listening bandwidth impairs temporal resolution only when high-frequency channels are lost (i.e., the temporal resolution capacity of high-frequency hearing channels are characteristically better than low-frequency channels).

Stuart and colleagues have demonstrated listeners with high-frequency hearing impairment perform poorer than normal-hearing controls with this word recognition in noise paradigm [11,43]. This poorer performance is interpreted to reflect some deficit in temporal resolution in these hearing-impaired listeners. The fact that listeners with noised-induced hearing impairment [9] and simulated high-frequency loss [32], performed significantly poorer only in interrupted noise, and not in continuous noise compared to normal-hearing listeners, is in agreement with the notion that signal audibility loss alone is not responsible. Additional data supplied by simulated hearing loss supports the notion that a restrictive listening bandwidth may affect temporal resolution performance. Scott et al., [33], demonstrated with increasing loss of highfrequency channel information the overall advantage in interrupted noise (i.e., release from masking) progressively deteriorated. Elangovan and Stuart [34], saw the contrary with increasing loss of low-frequency channel information simulating low-frequency hearing loss: the perceptual advantage in interrupted noise (i.e., the release from masking) was maintained with the restricted listening bandwidth. In other words, the Elangovan and Stuart [34], results and the present study imply that the deficit of low-frequency auditory channels does not significantly impair the temporal resolution to the extent that the loss of high-frequency auditory channels do.

In stark contrast to this case study, Stuart and Carpenter [43], revealed a selective deficit in auditory temporal resolution with an adult with a precipitous severe high-frequency unilateral hearing loss with the same battery of tests employed herein. Word recognition was excellent and not significantly different between the normal and hearing impaired ears in quiet. Word recognition performance was, however, significantly impaired in conditions of interrupted noise, reverberation, and time compression in the hearing-impaired ear relative to performance in the normal-hearing ear and that of normal-hearing controls. It was proposed that a restricted listening bandwidth was accountable in this case study in a detrimental way for the performance reduction on temporal resolution tests.

It is suggested that utilization of temporal resolution tasks could be of benefit in a clinical test battery. Such test battery may expose impairments that may not be detected in the presence of excellent word recognition in quiet. The use of interrupted noise as a competitor with monosyllabic stimuli is a viable alternative. Normative data is available for young normalhearing adults with NU-6 stimuli [11,32,39,44], older normal-hearing adults [11], preschool children [45] and school aged children [46]. Further, utilizing word recognition in time-varying backgrounds may help confirm an individual's complaint of difficulties understanding speech in adverse listening conditions (i.e., reverberant and or fluctuating noisy background conditions).

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