

Vowel Perception in Normal and Hearing Impaired Listeners

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Abstract

This study examined vowel perception in young adults of normal hearing and hearing impaired with a mild to severe sensorineural hearing loss (SNHL) listeners. Stimuli were presented at conversational level and were recorded, digitized, and edited syllables. The stimuli were broken down into varying transitions. Listeners discriminated the audio presented selected corresponding stimuli option based on his or her perception. Results showed that normal hearing listeners performed significantly better than the hearing impaired across three areas: Whole Syllable, Whole Vowel and Half Vowel; Initial Transitions; and Final Transitions. Listeners with hearing loss were consistently worse, suggesting a poorer representation of the vowel transition (or the vowel) to begin with rather than poorer temporal processing. Regardless of representation, the findings supported that hearing impaired listeners have more difficulties with vowel perception than normal listeners.

Introduction

The number of Americans with a hearing loss has doubled during the past 30 years according to American Speech and Hearing Association (ASHA, 2012). When assessing hearing loss, three areas must be examined: the type of hearing loss, degree and configuration. These areas can help determine which of the three hearing losses exist: conductive, sensorineural or mixed hearing loss. The primary focus of this study is to examine sensorineural hearing loss, which is the known to be the most common type of permanent hearing loss. Sensorineural hearing loss

occurs when there is damage to the cochlea or to the auditory nerve pathways from the brain to the inner ear. This reduces the ability to hear faint sounds and can muffle loud sounds as well. Possible causes can include: genetic factors, ototoxic drugs, aging, trauma, repeated exposure to loud noises or illnesses. Most often, SNHL is not surgically or medically corrected.

The purpose of this study is to determine whether listeners with SNHL can use formant transition cues to reliably identify vowels. Using participants with mild to severe sensorineural hearing loss compared to normal listeners ranging from ages 20-35, each were given a set of five syllables structures. Perceptual hearing studies have shown that listeners can identify coarticulated vowels with accuracy (Verbrugge, 1976) with varying consonant placements (Strange, 1989). However, previous research has shown that listeners with SNHL exhibit decreased vowel perception. It has been determined that the poorer performance of hearing impaired listeners on identification of vowel was related to their poorer frequency selectivity (Turner and Henn, 1989). Molis and Leek (2011) comment that normal hearing listeners typically require less contrast between spectral peaks and valley for accurate identification or discrimination of synthetic, vowel-like stimuli than do hearing impaired listeners. In their study on vowel identification by listeners with hearing loss (2011), both, an increased presentation level for normal hearing listeners and presence of hearing loss, produced a significant change in vowel identification with a major difference in vowel perception. Thus, it is likely due to reduce frequency selectivity among hearing impaired listeners.

Research in Dr. Hedrick's lab has shown that listeners with SNHL do not place as much perceptual weight on formant transitions in identifying consonant sounds as do listeners with normal hearing. Listeners with SNHL have reduced temporal integration, which may make perception of short-duration cues, such as formant transitions, difficult. There has been little work investigating vowel perception in listeners with SNHL, and even less as to what cues these listeners are using to identify vowels.

Method

Participants:

A total of 14 participants within the age range of 20-35 participated in this study. All participants were paid upon completion of the experiment. All listeners (both normal hearing and SNHL) had at least an eighth-grade education, were native speakers of English, and able to use a computer mouse to label the vowel sounds they heard while wearing headphones.

Ten listeners (6 males and 4 females) made up the normal hearing (NH) group. The normal listening participants had hearing sensitivity less than or equal to 25 dB HL in the right ear. These normal listeners were recruited from the Department of Audiology & Speech Pathology, the UTK campus, and from local churches and community organizations.

Four listeners (3 male and 1 female) made up the group with SNHL. Participants met the qualifications of a mild-severe loss of 30-80 dB HL in the 250-4000 Hz frequency range and provided a recent audiogram within the past year.

Listeners with SNHL were recruited from the Audiology Hearing Clinic, which is part of the University of Tennessee Speech and Hearing Center.

In addition, both groups filled out a case history form and those individuals with a cognitive, neurological, or learning deficits were excluded. All listeners provided written informed consent and were given a free hearing screening.

Stimuli:

Six naturally-produced stimuli were presented to the participants of the study. The stimuli consisted of a consonant-vowel-consonant (CVC) syllables spoken by the faculty advisor (Dr. Mark Hedrick). The syllable stimuli were all the same aside from the varying vowels. The complete stimuli structures were boob, bob, bub, beb, beeb and bab. The syllables were recorded, digitized, and edited using a software program to make stimuli. The stimuli were broken down into varying transitions. Each individual syllable sliced and pieced into nine sections: the whole syllable, the beginning transition, $\frac{1}{2}$ of the beginning transition, $\frac{1}{4}$ of the beginning transition, full central vowel, $\frac{1}{2}$ central vowel, ending transition, $\frac{1}{2}$ ending transition and $\frac{1}{4}$ of ending transition. This made a total of 54 stimuli, which participants were given 10 times in random order sets, for a total of 540 stimuli presented.

Procedure:

Listeners were tested individually in a sound-attenuated room and wearing headphones. Stimuli were presented via headphones into the right ear and presentations lasted roughly 2-3 seconds. Each stimulus was presented in a random order set 10 times. Stimuli were presented at a conversational level of 70 dB SPL for

the normal listeners and those with SNHL were shaped using the software program to mimic the gains of a hearing aid. The listeners used a computer mouse to select the corresponding word on the screen.

To verify the stimuli were at a comfortable listening level and familiarity with the stimuli, participants were given a practice run of the whole syllable structure. The participants listened to the whole word stimuli- beb, beeb, bub, bob, bab and boob. On the trial run, listeners were assured whether or not they answered correctly by a flash on the computer screen. A red flash indicated the response was incorrect. If the listener missed several during the trial, an additional trial test was given.

After that the trial, participants completed the actual experiment. A total of 54 stimuli were heard 10 times for a total of 540 presented stimuli. Total participation time was less than an hour. Due to the short duration and level of stimuli, no sounds were damaging to the listener's ears.

Results

For analysis purposes, portions of the stimuli were grouped according to initial transition portions, final transition portions, and whole syllable/vowel centers. For each of these three groupings, a three-way repeated-measures Analysis of Variance (ANOVA) was computed, with vowel (6) and duration of the portions (whole, half, or quarter transitions; whole syllable, whole vowel, or half the vowel) as the within-subject factors, and group (listeners with normal hearing or listeners with hearing loss) as the between-subject factor. The dependent variable was number of correct vowel identifications. To guard against violations of sphericity,

Huynh-Feldt corrections were used. Results for each of these analyses are listed below.

Whole Syllable, Whole Vowel and Half Vowel:

For the whole syllable/whole vowel only/half the vowel, the ANOVA yielded a significant main effect of vowel [$F(2.778, 33.332) = 5.701, p < 0.001$], a significant vowel x group interaction [$F(2.778, 33.332) = 3.139, p = 0.041$], a significant effect of duration [$F(1.759, 21.107) = 30.988, p < 0.001$], a significant duration x group interaction [$F(1.759, 21.107) = 9.838, p = 0.001$], a significant phoneme x duration interaction [$F(6.844, 82.126) = 3.649, p = 0.002$], and a significant three-way interaction of vowel, duration, and group [$F(6.844, 82.126) = 5.117, p < 0.001$]. There was also a significant main effect of group [$F(1,12) = 14.088, p = 0.003$, partial eta squared .540]. In almost all conditions, the listeners with hearing loss performed worse. For some stimuli (e.g. beeb, boob, bub), the listeners with hearing loss simply did worse for all three durations, particularly worse for the half-center duration. For “bob” (Figure 1), the listeners with hearing loss did worse as the duration shortened, and for “bab” (Figure 2), the listeners with normal hearing became much worse with the half-center duration and approximated performance of listeners with hearing loss. These results suggest that listeners with hearing loss may have a poorer internal representation of the vowel, perhaps from inability to phase-lock or synchronize with the vowel waveform. Similar results have been shown from VIIIth nerve recordings of animals given a noise-induced hearing loss. Typically the listeners with hearing loss did poorer for all durations of the vowel, not simply the shorter durations. This coupled with a usual finding of decreasing

performance with decreasing duration would suggest increasing difficulties with internal representation as the vowel information was reduced, implying some form of degraded temporal processing. That the listeners with normal hearing did worse with decreasing duration for only one vowel (the /ae/ of “bab”) suggests that the given production selected may have caused difficulty for some listeners. The fact that each of the patterns varied across vowels implies some form of difficulties with more central phoneme processing – the largest discrepancies between normal-hearing and hearing-impaired data points occurred for the half-center duration with the vowels /u, U, and a/ - all of which typically have F2 values in the 800-1200 Hz range. So, the main difficulty of the listeners with hearing loss was not from vowels having a higher-frequency F2 (like /i/ or /I/), but rather a difficulty in spectrally separating out vowels with similar formant values. Two of these three vowels are vowels at the points of the vowel quadrilateral – which suggests that the internal templates for vowels in listeners with hearing loss are not as firmly anchored in perceptual space as in listeners with normal hearing. This lack of anchoring may make perception of all vowels subject to some uncertainty on the part of the listeners with hearing loss.

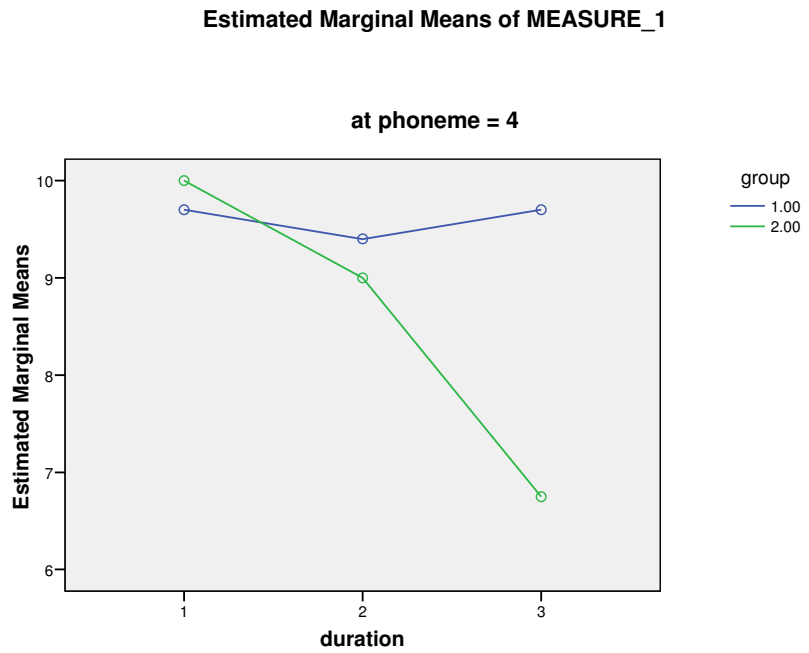


Figure 1: Bob Center Word

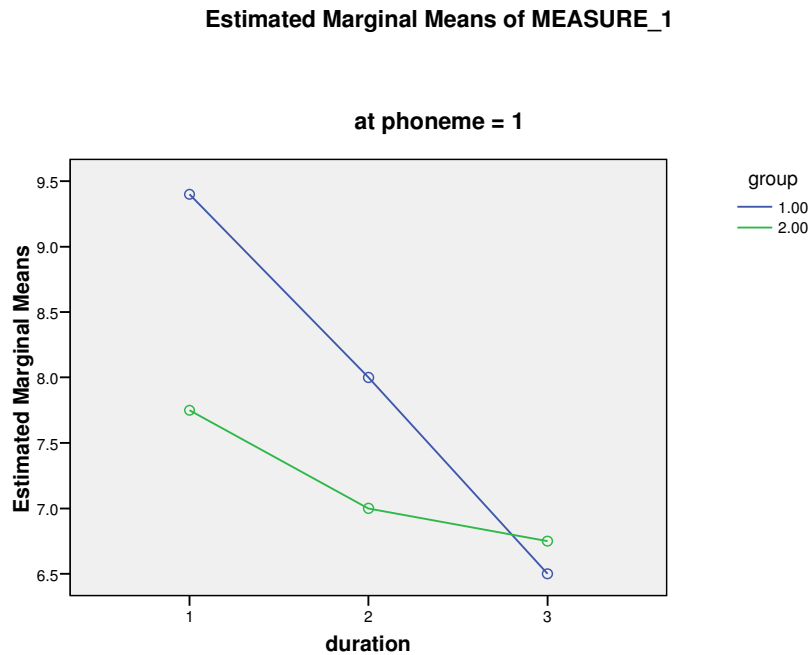


Figure 2: Bab Center Word

Initial transitions:

For the initial transitions into the vowels, the ANOVA yielded a significant main effect of vowel [$F(2.538, 30.455) = 13.711, p < 0.001$], a significant effect of duration [$F(1.639, 19.670) = 159.778, p < 0.001$], a significant vowel x duration interaction [$F(10, 120) = 5.408, p < 0.000$] and a significant group main effect [$F(1.12) = 9.251, p = 0.010$, partial eta squared .435]. The vowel x duration interaction may be explained by the fact that some vowels yielded similar performance whether the whole or half transition was presented, but with a large decrement using the quarter transition (e.g. /i, a, u/ Figure 3, 4 and 5) whereas other vowels showed a more gradual decline in performance as duration of the transition was reduced. It may be that the vowels at the points of the vowel quadrilateral are more resistant to changes in transition duration than mid-value vowels along the quadrilateral. Listeners with hearing loss were consistently worse, suggesting again a poorer representation of the vowel transition (or the vowel, for that matter) to begin with rather than poorer temporal processing per se. These results are similar to those found earlier for use of transitions for consonant perception (e.g. Hedrick & Jesteadt, 1997).

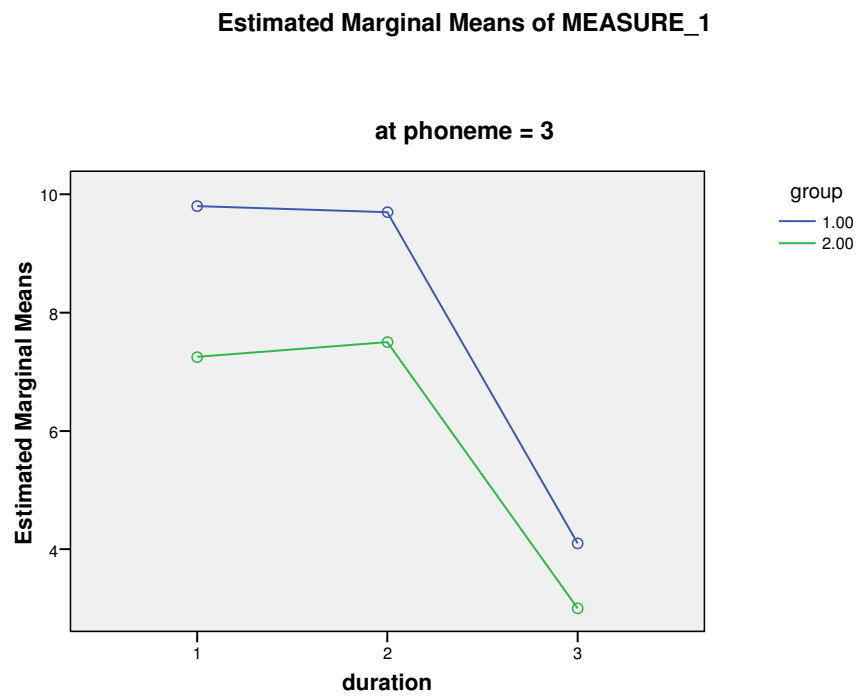


Figure 3: Beeb Initial Transition

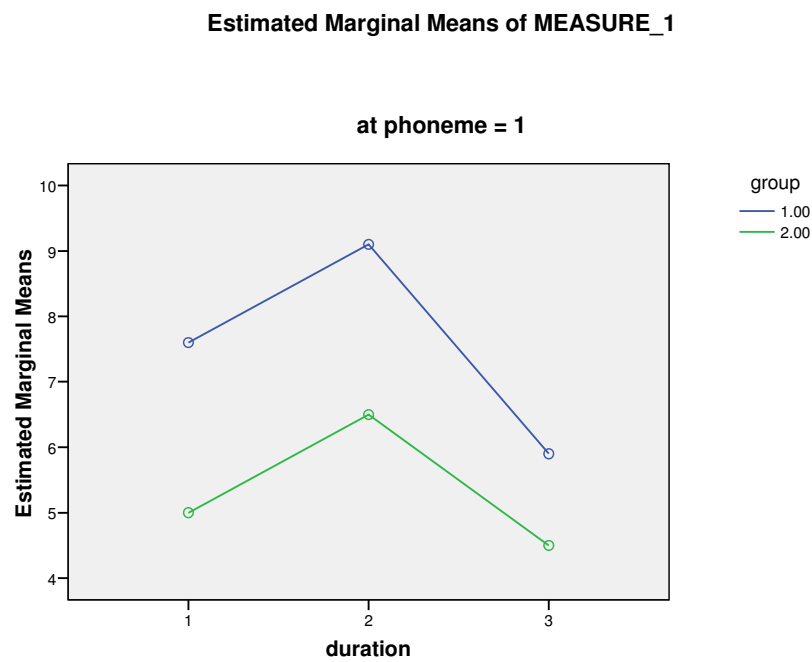


Figure 4: Bab Initial Transition

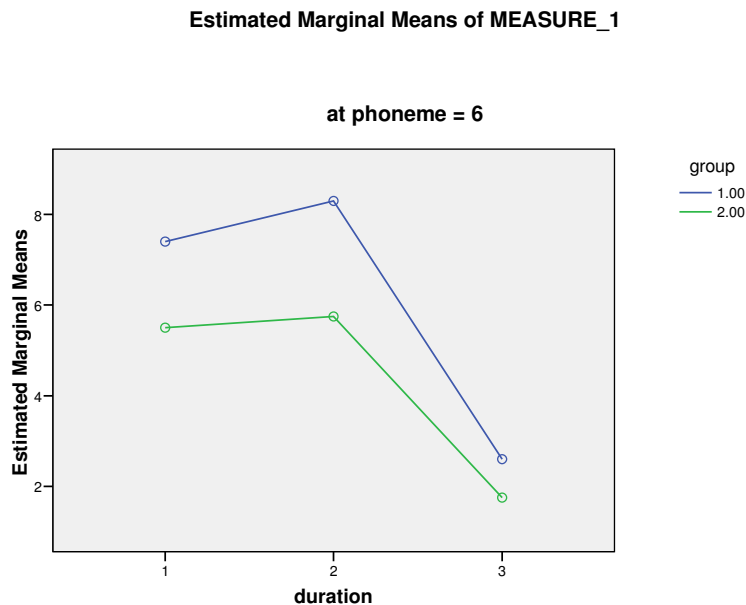


Figure 5: Bub Initial Transition

Final Transitions:

For the final transitions out from the vowels, the ANOVA yielded a significant main effect of vowel [$F(3.241, 38.889) = 9.362, p < 0.001$], a significant phoneme x group interaction [$F(3.241, 38.889) = 3.814, p = 0.015$], a significant effect of duration [$F(1.691, 20.295) = 162.470, p < 0.001$], a significant duration x group interaction [$F(1.691, 20.295) = 8.090, p = 0.004$], a significant phoneme x duration interaction [$F(9.323, 111.880) = 6.110, p < 0.001$], and a significant vowel x duration x group interaction [$F(9.323, 111.880) = 2.354, p = 0.017$]. There was also a significant main effect of group [$F(1,12) = 20.686, p = 0.001$, partial eta squared .633]. Similar to findings above, the listeners with hearing loss fared worse, there was a large decrement for some vowels to the quarter transition (e.g. /i, a, u/ Figure 6, 7, 8) whereas other vowels showed a more gradual decline in performance as duration of the transition was reduced.

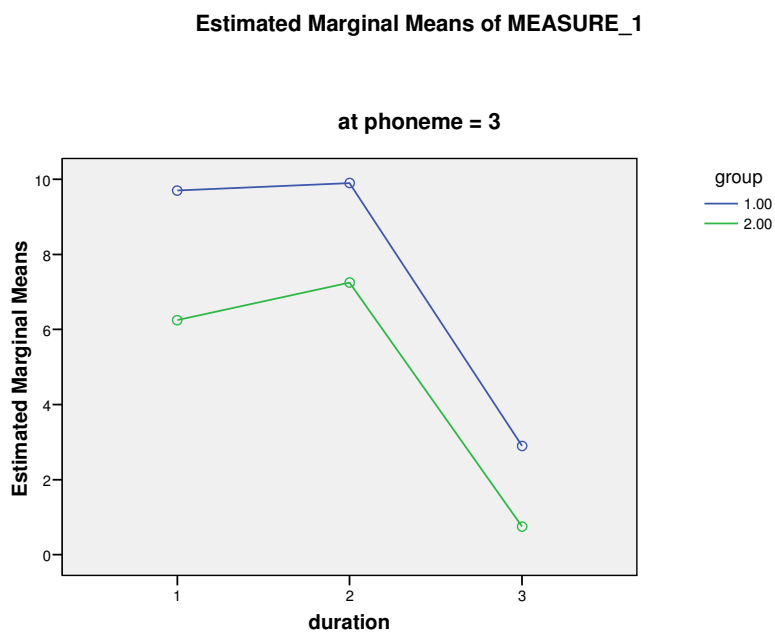


Figure 6: Beeb Final Transition

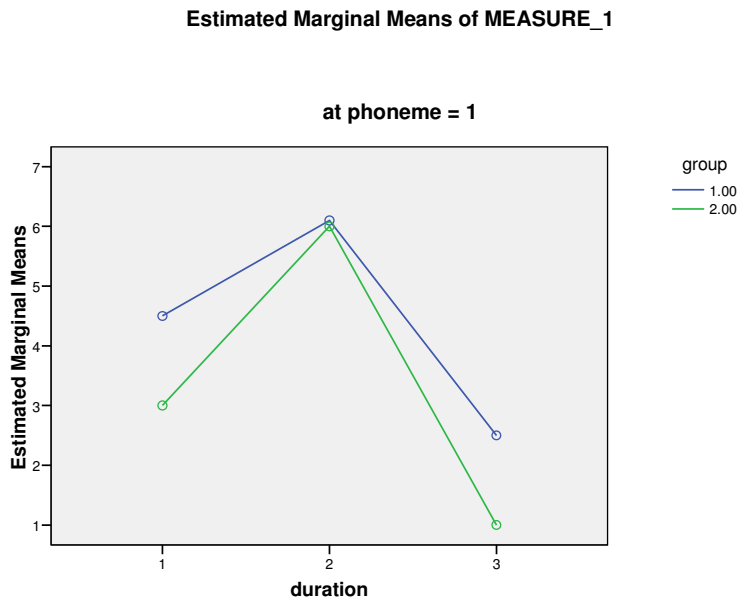


Figure 7: Bab Final Transition

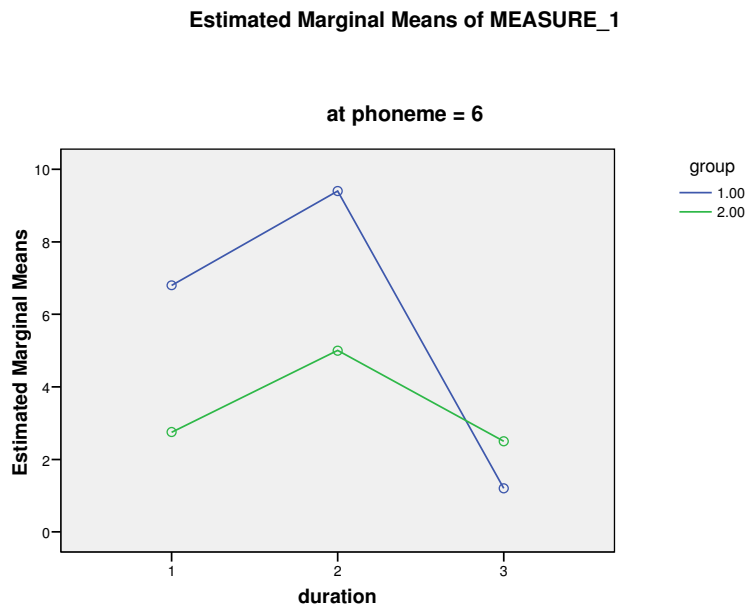


Figure 8: Bub Final Transition

Conclusion

Significant findings were found all across the board with the most significant finding was between three-way interaction of vowel, duration, and groups of NH versus SNHL. The results indicate that hearing impaired listeners performed worse than normal listeners with the biggest differences amongst the $\frac{1}{4}$ transitions. Even among the vowel stimuli, there were discrepancies amongst the different vowels. This can be attributed to certain vowels at the points on the vowel quadrilateral. Listeners with hearing loss were consistently worse, suggesting a poorer representation of the vowel transition (or the vowel) to begin with rather than poorer temporal processing. Regardless of representation, the findings supported that hearing impaired listeners have more difficulties with vowel perception than normal listeners.

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