HEARING LOSS AND THE PHONETIC CONTEXT EFFECT

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In order to gain a better understanding of how hearing loss influences speech perception, the influence of phonetic context on vowel identification was tested under simulated hearing loss conditions. Participants (*n*=17) were presented vowels along the /ɛ/ - /ʌ/ acoustic continuum in /bVb/ and /dVd/ contexts and instructed to indicate which vowel they heard in normal hearing, and mild and severe simulated hearing loss conditions. It was hypothesized that a phonetic context effect would be observed in the normal hearing condition, diminish in the mild hearing loss condition, and disappear in the severe hearing loss conditions. The percent of /ʌ/ responses were calculated and the categorical boundary was estimated for each context and compared for differences within and across conditions. Contrary to expectations, no context effect was found for the normal hearing and mild hearing loss conditions. However, an unexpected phonetic context effect was observed in the severe hearing loss condition. These results were difficult to interpret given the lack of a significant context effect in the normal hearing condition and suggested possible interference introduced by test or stimulus procedures. It should be noted, however, that 9 of the 17 participants did demonstrated the effect in the normal hearing condition, with many maintaining the effect across both hearing loss conditions.

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PREFACE

This thesis was made possible by the generosity of Dr. Sheila Pratt, who donated much of her time and resources to help guide me in this project. I am so grateful for her devotion to sharing her extensive research knowledge with students at every academic level. Financial support for this project was also provided by the SHRS Research Development Fund.

1.0 INTRODUCTION

1.1 CONTEXT AND SPEECH PERCEPTION

Context is an invaluable tool when interpreting many types of sensory information. For listening in particular, the brain relies heavily on contextual information to process the sounds that it hears. On a semantic level, listeners often use clues about subject matter to help them discriminate between words that sound similarly. For instance, if an individual hears a word that could be perceived as “vote” or “boat” during a conversation about a weekend beach trip, a person likely will use context clues to decide that the word was “boat”. Likewise, research suggests that our brains use surrounding phonetic information to process speech sounds (Holt, 2006; Holt & Lotto, 2002). This means that with ongoing speech the brain attends to coarticulation and other phonetic cues to determine the identity of phonemes and morphemes. For example, when /g/ and /d/ are made acoustically ambiguous, listeners more often identify the sounds as /g/ if it follows the syllable /al/, and /d/ if it follows the syllable /ar/ (Mann, 1980; Mann & Repp, 1980). The role of this type of contextual information is critical to the study of speech perception, because phonemes are rarely found in isolation during speech.

The spectral nature of vowel formants is also a strong cue for the perception of both vowels and consonants. Vowel formants are narrow regions of heightened intensity associated with sources of constriction within the vocal tract, and the relative relationship between formants within a vowel is a strong perceptual cue for vowel identity. Also, the format transitions associated with articulation in and out of a vowel are strong cues for preceding and subsequent consonants as well as the vowel itself. As a result, vowels with the same formant center frequencies can be heard differently in isolation as compared to a Consonant-Vowel-Consonant (CVC) and other syllable contexts. Examining the unique spectral characteristics of these formant frequencies helps explain some of the perceptual differences that occur between vowels in isolation and continuous speech, and emphasizes the importance of contextual information in the perception and processing of continuous speech.

Because vowels are rarely produced in isolation, they also are rarely produced in their canonical or target form. Instead, vowels often are under-stressed when produced in context or ongoing speech to economize oral production and communication. This economy results in assimilation - the process by which individuals produce speech sounds that are acoustically similar to the sounds that come before or after it. (Lindblom, 1963; Lindblom & Studdert-Kennedy, 1967). Lindblom (1963) studied assimilation to demonstrate the importance of surrounding phonetic context on Swedish vowel identity in CVC patterns such as /bVb/, /dVd/, and /gVg/, and his results confirmed that the vowels do not reach target frequencies when they occur in these contexts.

Lindblom and Studdert-Kennedy (1967) later studied categorization of the vowel continuum of /ʊ/ - /ɪ/ in a /wVw/ and /jVj/ context and found that vowel identity depended on phonetic environment and vowel duration. Listeners were more likely to perceive a vowel sound as /ʊ/ in a /jVj/ context and /ɪ/ in a /wVw/ context. The influence of consonant context in this example succeeded in demonstrating that the direction and rate of formant transitions into and out of a vowel plays a significant role on vowel identification. Furthermore, it was noticed despite being under-stressed and not reaching target formant frequencies, the vowels were correctly identified in the CVC contexts. These results suggested that formant transitions and the presence of surrounding phonetic context are used to compensate for assimilation in vowel identification (Lindblom, 1963; Lindblom & Studdert-Kennedy, 1967). That is, consonants adjacent to vowels (and other phonetic contexts) influence perception by helping listeners compensate for coarticulation.

1.2 THEORETICAL PERSPECTIVES OF SPEECH PERCEPTION

Investigations of the role of coarticulation, along with research on other phenomena like categorical perception and speech perception development and learning, have stimulated studies looking into the fundamental characteristics and functions of speech perception. Various theories of speech perception have been developed but two general approaches have been used to account for the how listeners perceive and use coarticulation in the perception of speech. These include the gestural models such as the Motor Theory (Liberman, Cooper, Shankweiler, & Studdert-Kennedy, 1967; Liberman & Mattingly, 1985) and the Direct Realist Theory (Fowler, 1986; 1996), which connect speech perception to articulation rather than acoustics; and more general auditory approaches as described by Diehl, Lotto and Holt (2004) and Lotto and Holt (2015), which focus more on the acoustics of speech sounds and how they are processed in various contexts by the auditory system. That is not to say, however, that speech perception occurs within the auditory system independently of the language, memory, attention and other cognitive functions; or that the motor-speech mechanism and auditory system function autonomously. The research suggests otherwise, and current prominent models of speech perception and speech production consider the interactions between audition and the speech production mechanism to be critical (Guenther & Vladush, 2012; Hickok, Houde, & Rong, 2011; Hickok & Poeppel, 2007).

The gestural theories attribute speech perception to our knowledge of articulation and the production of speech sounds. For example, by making connections between second-formant (F2) transitions and place of articulation for given sounds, Liberman et al. (1967) claimed that it is the understanding of acoustic consequences of articulations that account for our ability to identify individual speech sounds despite substantive acoustic variability in ongoing speech. That is, our understanding of the mechanisms used to produce speech direct our perception of speech, so that listeners perceive linguistically relevant "objects" rather than signals transformed by the auditory system (Fowler, 2015). Liberman and Mattingly (1985) further attempted to explain how the intrinsic knowledge of speech gestures allows for recovery of coarticulation, when several speech production movements are contributing to a given signal at one time. They found that a single gesture can signify the identity of different sounds in different contexts. They used the Consonant-Vowel (CV) context of /di/ and /du/ as examples. The /d/ has a rising F2 transition moving into the vowel /i/ in the syllable /di/, and a falling F2 transition into the vowel /u/ in the syllable /du/, yet they argued that these two different acoustic events represent the same /d/ gesture. Liberman and Mattingly also argued that recognition of the /d/ gesture requires a complex relationship between overlapping gestures and an understanding of how they are produced differently in different phonetic environments. They described the process as a complex mapping and suggested that humans have a speech decoding mechanism that affords them the ability to perceive the same consonant regardless of gestural and phonetic context.

Fowler (1996; 2015) also explains speech perception from a gestural perspective with the Direct Realist Theory, which stipulates that gestural information is available within the acoustic signal although the recruitment of the motor system is not required for perception (Fowler, 2015). In this way, the theory claims that speech perception is a direct response to the motor act, rather than acoustic variations and contrasts found in the speech acoustic signal. For example, a listener will identify /p/ in the syllable /pa/ because it is directly associated with the lip movements that contribute to the production. In this way, the Direct Realist Theory is distinct from the Motor Theory in that it attributes speech perception to a physical reaction to a signal rather than a neural process of decoding.

The Direct Realist Theory also looks at coarticulation in terms of the temporal overlap of different sounds or “coproduction” rather than assimilation. It argues that all components of a sound are separate acoustic events that occur simultaneously instead of merging to create a single gesture (Fowler, 1980, 1981; Fowler & Smith, 1986). An example that supports coproduction is when a vowel is followed by a nasal consonant. In this context, the vowel usually is nasalized, but many listeners will associate the nasalization with the consonant and not with the vowel (Krakow et al., 1988). The argument is that that the vowel remains separate from the nasal consonant because the sounds are perceived as individual phonemes, even though motorically and acoustically they interact and are not truly distinct.

Over time the gestural theories faced substantive challenges. They attempted to explain perceptual patterns (phonetic context effects, categorical perception, etc.) as unique to speech or to the human vocal tract, but these effects also have been observed with nonspeech stimuli and with nonhuman subjects. The influence of /al/ or /ar/ context on identification of /d/ and /g/, was found in Japanese quail by Lotto, Kluender, and Holt (1997), which showed that animals with no knowledge or experience with the human vocal tract and human coarticulation can effectively use phonetic context to identify consonants. The effects of /al/ and /ar/ context on /d/ and /g/ identification also has been demonstrated with non-speech stimuli. Lotto and Kluender (1998) used non-speech contexts that were spectrally similar to the /ar/ and /al/ and found a similar effect. The finding with non-speech stimuli discredited the idea of a speech-specific decoder proposed by Motor Theorists. The idea that phonetic context effects are not specific to speech or to humans created significant difficulties for the theories of speech perception that are based on gestures, and thus paved the way for a more general acoustic/auditory approach to speech perception.

The general auditory approach emerged to counter the idea of specialized mechanisms and gestures. This approach suggests that speech sounds are processed by the same auditory mechanisms as non-speech sounds. For example, in the /di/ versus /du/ example of Liberman and Mattingly (1985), identification of the initial /d/ can be explained as a function of capability of the auditory system to recognize and classify complex acoustic stimuli that need not be speech (Diehl et al., 2004; Holt, 2009). A general auditory approach also explains why the phonetic context effect can be observed with non-speech contexts (Holt et al., 2000; Holt, 2009), and why animals with no previous experience with speech or speech mechanisms can learn to use phonetic context to influence phoneme identification and account for coarticulation (Lotto et al., 1997).

1.3 SPECTRAL CONTRAST

Research conducted by Holt and colleagues (Holt et al., 2000; Holt & Lotto, 2002; Holt, 2006) argues that the surrounding spectral cues in speech signals are critical to the recovery and resolution of coarticulation in speech perception. This notion is consistent with Lindblom and Studdert-Kennedy (1967) who found that the spectral characteristics of adjacent consonants influenced vowel identification as reflected in shifts in categorical boundaries. So too, this process is involved when /al/ and /ar/ influence the perceptions of ambiguous /da/ and /ga/ syllables where the perceptual system compensates for the assimilation by shifting in the opposite direction (Mann, 1980; Mann & Repp, 1980). Similarly, Holt et al. (2000) found that in the context of /b/, vowels synthesized to represent the /ε/ - /ʌ/ acoustic continuum by modifying the F2 formant frequency were more likely to be perceived as /ε/, whereas the same vowels are more likely to be perceived as /ʌ/ in the context of /d/. This compensation typically is evidenced by a shift in the categorical or perceptual boundary of sound along its acoustic continuum. In the case of the Holt et al. study the perceptual boundary for the /ε/ - /ʌ/ continuum was lower in frequency in the context of /b/ than in the context of /d/.

In additional experiments, the impact of signal frequency characteristics in the phonetic context effect also was examined by comparing the speech cues to non-speech analogues (Coady et al., 2003; Holt, 2005, 2006; Holt et al., 2000; Stephens & Holt, 2003). Holt et al. (2000) also controlled for other possible influences like phonetic labeling and auditory grouping, and these context effects remained evident. By showing that listeners were still able to use phonetic context for vowel identification when the possibilities for phonetic labeling and auditory grouping were removed from the experimental design, they demonstrated the importance of spectral contrast in accommodating for coarticulation. To bolster their argument they also found a diminution of the phonetic context effect when spectral content was less consistent and salient (i.e. in voiceless consonant contexts), which further supported the dependence on spectral contrast and the notion that speech is first processed through a central auditory mechanism such as a spectral processor. It also should be noted that an early-stage spectral processor or some type of early signal transformer is common to many models of speech and word perception (e.g., Jusczyk, 1986; Klatt, 1979; McClelland & Elman, 1986).

1.4 HEARING LOSS

Hearing loss is common in the general population with approximately 16% of adults in the United States having a hearing loss in the frequency range critical for the perception of speech (Agrawal, Platz, & Niparko, 2008). It is considered a high-incidence disorder in infants and young children, and the third most common chronic health condition in adulthood and nearly ubiquitous with aging (National Center for Health Statistics, 2010). In a study of 3556 adults from Beaver Dam, Wisconsin, Cruickshanks et al. (1998) found a hearing loss prevalence of 21% in adults ages 48-59 years, 44% for ages 60-69, 66% for ages 70-79, and 90% for ages 80-92. Other studies of age-related hearing loss in the United States and elsewhere have produced similar results - finding approximately two out of three adults aged 70 years and older having a hearing loss (Agrawal et al., 2008; Genther et al., 2013; Helzner et al., 2005; Pratt et al., 2009; Sindhusake et al., 2001).

The typical hearing loss configuration in adults is a bilateral high frequency sensory loss with normal or near normal hearing in the low frequencies (Cruickshanks et al., 1998; Moscicki, Elkins, Baum, & McNamara, 1985). The primary consequence of hearing loss is impaired speech perception and communication although audiometric configuration is only modestly predictive of the difficulties that people have hearing speech (Bilger & Wang, 1976). In general, the greater the hearing loss the more speech perception is impacted (Boothroyd, 1984; Dubno, Lee, Klein, Matthews & Lam, 1995). Correspondingly, speech perception tends to deteriorate with age because the prevalence and magnitude of hearing loss also increases with age (Cruickshanks et al., 1998a; Moscicki et al., 1985). The magnitude of the pure-tone hearing threshold shift (or reduction in audibility) explains most speech perception impairment in adults with hearing loss, but gender and (in some studies) age have been found to also account for a significant proportion of the variance (Dubno, Lee, Matthews & Mills, 1997; Wiley et al., 1998). It has been argued that differences in cognitive processes, such as language processing or auditory attention and memory, may account for gender and age effects observed in previous studies (Humes & Roberts, 1990).

The impact of hearing loss on speech perception is well studied and generally shows that consonant speech cues representing place information are most susceptible to hearing loss, followed by manner and voicing (Bilger & Wang, 1976; Boothroyd, 1984; Walden & Montgomery, 1975; Phatek, Yoon, Gooler, & Allen, 2009). Low intensity, unvoiced, and faster consonants, particularly in the final word position, also tend to be susceptible to hearing loss. In contrast, vowel identification and the processing of prosodic information is robust in the face of significant hearing loss, but as discussed previously, the distinctions between vowels and consonants, and segmental and prosodic parts of speech are somewhat artificial in that they are rarely produced in isolation or independently.

For the purposes of current study, decreased frequency selectivity and distortion associated with sensory hearing loss is justification for looking at the impact of hearing loss on the phonetic context effect. Reduced access to intact spectral information likely results from even mild hearing losses, yet the ability to use spectral context to aid speech perception has not been investigated in persons with hearing loss. Even with amplification (e.g., with hearing aids), speech signals are spectrally compromised and distorted.

In order to move towards a more complete understanding of speech perception in individuals with hearing loss, it may be beneficial to determine whether they have a weakened ability to use spectral context to accommodate coarticulation. Understanding this relationship could have important implications for identifying specific deficits and targets for technological and medical treatments and behavioral remediation. As such, the aim of this study is to examine how simulated hearing losses at mild and severe levels of impairment impact the use of the phonetic context effect by adults as an aid in vowel identification.

2.0 HYPOTHESIS

The experimental hypotheses as stated in the null are as follows:

1. Simulated hearing loss does not interfere with the phonetic context effect as reflected in boundary shifts in vowel identification along the /ε/ - /ʌ/ acoustic continuum within /bVb/ and /dVd/ syllable contexts.
2. Simulated hearing loss severity does not differentially influence the phonetic context effect as reflected in boundary shifts in vowel identification along the /ε/ - /ʌ/ acoustic continuum within /bVb/ and /dVd/ syllable context.

As found by Holt et al. (2000), it is expected that adult listeners under normal hearing conditions will rely on spectral contrast when identifying vowels within CVC contexts. That is, they will identify more /ʌ/ vowels in a /dVd/ context and more /ε/ vowels in a /bVb/ context, thus demonstrating differences in the vowel perceptual boundary as a function of the phonetic context. It also is expected that this pattern of identifying more /ʌ/ or /ε/ vowels in different consonant contexts will be less prominent when the stimuli are processed through a mild hearing loss simulator, and absent when processed through a severe hearing loss simulator. This pattern will demonstrate that individuals experience a weakened ability to use spectral contrast for vowel identification when a hearing loss is present. However, if a phonetic context persists with mild and severe hearing losses it is possible that some type of cue shifting or trading may be active.

3.0 METHODS

3.1 PARTICIPANTS

The participants consisted of 17 normal-hearing young women, aged 18 to 25. The participants were recruited through announcements in undergraduate classes in the Department of Communication Science and Disorders at the University of Pittsburgh. They did not receive remuneration, but many received extra-credit from their course instructors. The number of participants was estimated based on a repeated measures ANOVA, a moderate effect size consistent with previous research, and an alpha of .05. The study was approved by the University of Pittsburgh IRB and all participants signed a consent form prior to participation.

Six participants were excluded from this study. One participant was removed because of inadequate data storage by the computer program used in the experiment, and five others were dismissed because they did not meeting the inclusion criteria. Participant information is shown in Table 1.

Table 1. Participant Demographic Information

Participant	Age	Sex	Race	Education Level
1	21	Female	White	some college
5	22	Female	White	some college
10	22	Female	White	some college
12	23	Female	White	some college
13	21	Female	White	some college
15	22	Female	White	some college
17	22	Female	White	some college
19	22	Female	White	some college
22	21	Female	White	some college
23	22	Female	White	some college
27	22	Female	White	some college
28	22	Female	White	some college
29	22	Female	African American	some college
32	22	Female	White	some college
35	21	Female	White	some college
36	22	Female	White	some college
37	21	Female	White	some college
	Mean = 21.76	F=17, M=0		

3.2 SCREENING PROCEDURES

The screening procedures for all participants consisted of otoscopy, tympanometry, a pure-tone hearing screen, a word recognition in noise test, and a non-word repetition task. Otoscopy was completed to confirm that the ear canals were sufficiently clear for tympanometry. To document normal middle ear function tympanometry with a 226 Hz probe-tone was completed for both ears using a screening tympanometer (Sentiero, SOD100497). The pure-tone hearing screen was administered within a sound booth under insert earphones with 500, 1000, 2000, 4000 and 8000 Hz pure-tones generated from a diagnostic audiometer (Grason-Stadler, GSI 16) and presented at 25 dB HL. Word recognition in noise was assessed with the Words in Noise Test (Wilson, Carnell, & Cleghorn, 2007) to confirm normal speech perception skills, and a non-word repetition task (Dollaghan & Campbell, 1998) was used to screen for normal auditory linguistic, and speech recognition and production skills. The pre-recorded non-words were presented from computer via circumaural earphones (Radio Shack, 04A08) at 65 dB SPL. The responses were recorded and then transcribed offline. A background questionnaire also was completed to obtain basic demographic information and speech, language, and hearing history (see Appendix).

Table 2. Words in Noise Thresholds (dB S/B)

Participant	Left Ear	Right Ear
1	2.0	2.8
5	1.2	5.2
10	5.2	6.0
12	3.6	5.2
13	3.6	4.4
15	5.2	5.2
17	6.0	6.0
19	5.2	2.8
22	2.8	6.0
23	6.0	5.2
27	5.2	5.2
28	6.0	4.4
29	6.0	6.0
32	2.0	1.2
35	6.0	5.2
36	5.2	3.6
37	3.6	5.2
	Mean = 4.40	Mean = 4.68

3.3 STIMULI

The acoustic stimuli were used previously by Utz (2009) and were based on the stimuli used by Holt et al. (2000) in a similar study. They consisted of /bVb/ and /dVd/ syllables with vowels that spanned the /ε/ - /ʌ/ acoustic continuum. Isolated vowels also were constructed for the current study normal identification without regard to context. The center frequency of the vowel F2 formants varied from 1210 to 1760 Hz in 50 Hz steps. The vowels were created first in isolation and then in the two consonant contexts using a Klatt parametric synthesizer (Klatt, 1980; Klatt & Klatt, 1987) embedded within the HLsyn formant synthesizer program (Sensimetrics, v2.2). The two contexts were associated with two distinct F2 onset and offset loci consistent with /b/ and /d/. For the /bVb/ stimuli, the F2 onset and offset was relatively low in frequency (800 Hz), whereas for /dVd/ stimuli a higher frequency transition locus (2270 Hz) was used, thus providing the two distinct spectral contexts. The sound files were then processed through a hearing loss simulator (HeLPS, Sensimetrics Inc.) to create a mild and a severe high-frequency hearing loss. The simulator low-pass filtered the sounds and added noise and distortion during the process. The threshold shift and speech confusions caused by the hearing loss simulator had been validated through previous work in the lab. The stimuli were then high-frequency amplified with a 1/3rd octave graphic equalizer using a 1/3 gain rule to ensure audibility and simulate a linear hearing aid. All stimuli were then equated for average RMS to ensure comparable audibility.

Table 3. Simulation Threshold Values (in dB HL)

Condition	Signal Frequency (Hz)					
	250	500	1000	2000	4000	6000
Normal	0	0	0	0	0	0
Mild	15	25	30	35	35	40
Severe	25	35	50	70	75	80

3.4 PROCEDURES

SuperLab laboratory software on a laptop computer was used to present all stimuli and record responses. The stimuli were directed from the computer's audio port through an earphone amplifier (Behringer MiniAMP, AMP800) and then presented through circumaural earphones (Radio Shack, 04A08) at 65 dB SPL as calibrated on KEMAR fitted with an artificial ear coupler. All data was collected in a quiet laboratory testing environment.

All participants were first trained to use the computer response system to identify the endpoint vowels /ε/ and /ʌ/. They were instructed to use a computer mouse keypad and click the left button (marked "eh" for /ε/) or the right button (marked "uh" for /ʌ/) depending on which vowel they heard. For each response, the computer screen provided feedback on correctness (e.g.,"Correct" or "Sorry, not correct"). Each participant was first trained with the endpoint vowels in isolation, and then in a /bVb/ and /dVd/ context. The training order for the two contexts was randomized across subjects. Each training block consisted of 10 trials.

Following successful training, the participants were administered the experimental procedures. They first were presented the stimuli in a normal hearing condition, in which a hearing loss was not simulated. The vowels in isolation were first present to assess perception without the consonant context. After a 5 minute break the vowels were presented in context. As with the training, the participant responded to each presentation by pushing the "eh" button or the "uh" button but no feedback was provided. The stimuli were presented in blocks according to context (/bVb/ or /dVd/). The blocks contained 10 randomly ordered presentations of the 12 stimuli, totaling 120 trials for per block. The blocks per context were randomized.

After completing the normal hearing condition, the participants completed the mild and severe hearing loss conditions. The order for these two conditions was randomized across participants so that each participant completed the experimental blocks in both contexts for the mild hearing loss and the severe hearing loss stimuli. After each experimental block, the participants were given mandatory breaks lasting at least 5 minutes each to reduce any interference effects across blocks and conditions.

4.0 ANALYSES

For each hearing condition and context the percentage of /ʌ/ responses were calculated across the different F2 center frequencies. A Probit analysis (Finney, 1971), with a base-10 log transform (SPSS, v 23) was applied to the individual data in order to estimate the 50% point on the categorical boundaries (identification threshold). A within-subjects ANOVA was then applied to the boundary estimates and post-hoc t-tests for related samples were used as needed with the alpha controlled at the .05 level.

5.0 RESULTS

The within subjects ANOVA applied to the boundary frequencies showed a significant main effect for hearing loss status, F=6.642, df=2, p=.004, η_p^2=.293, and a hearing loss by context interaction, F=6.496, df=2, p=.004, η_p^2=.289, but not for context. The hearing loss effect and hearing loss by context interaction were largely due to differences between the mild and severe hearing loss conditions. The boundaries were lower in the mild hearing loss condition overall but as can be seen in Figure 1, the relative difference between contexts also flipped across these two conditions.

The lack of a main effect for context was evident in the normal hearing and the mild hearing loss conditions. In contrast to the Utz (2009) study that used the same stimuli and procedures, there was no shift in the boundary locations and the identification functions were very similar. It can be seen in Figure 2 that the participants had clear categories but that they were not influenced by the consonant context. It was expected that the F2 boundary would be higher in frequency in the /dVd/ context than in the /bVb/ context - that is, the listeners were expected to identify more /ʌ/ than /ɛ/ vowels in the /dVd/ context than in the /bVb/ context. This pattern can be seen for the Utz (2009) data in Figure 3 in comparison to the data from the current study. The lack of a context effect in the normal hearing condition is problematic for interpreting the results of the other two conditions because it is unclear what may have contributed to the lack of the known and predicted effect.

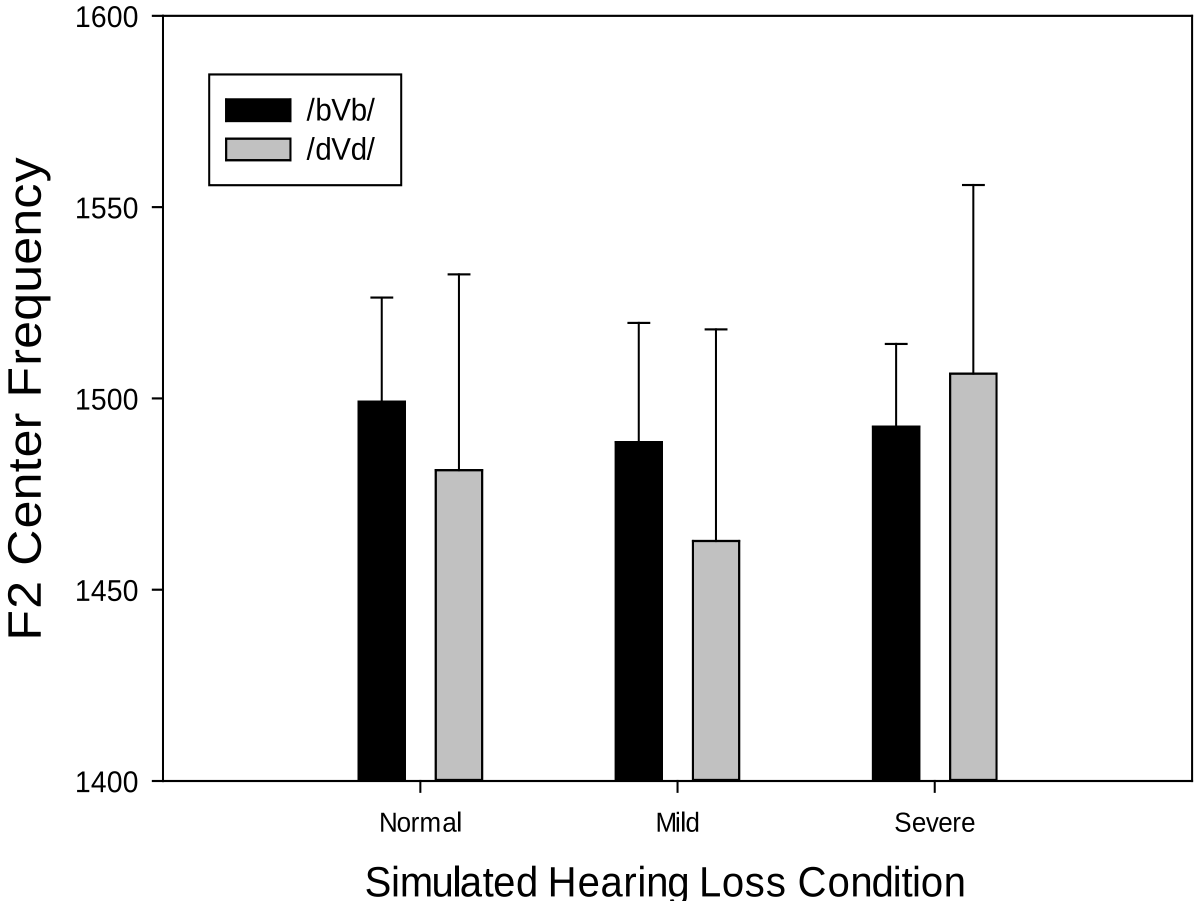

Figure 1. Mean Categorical Boundaries and +1 Standard Deviations

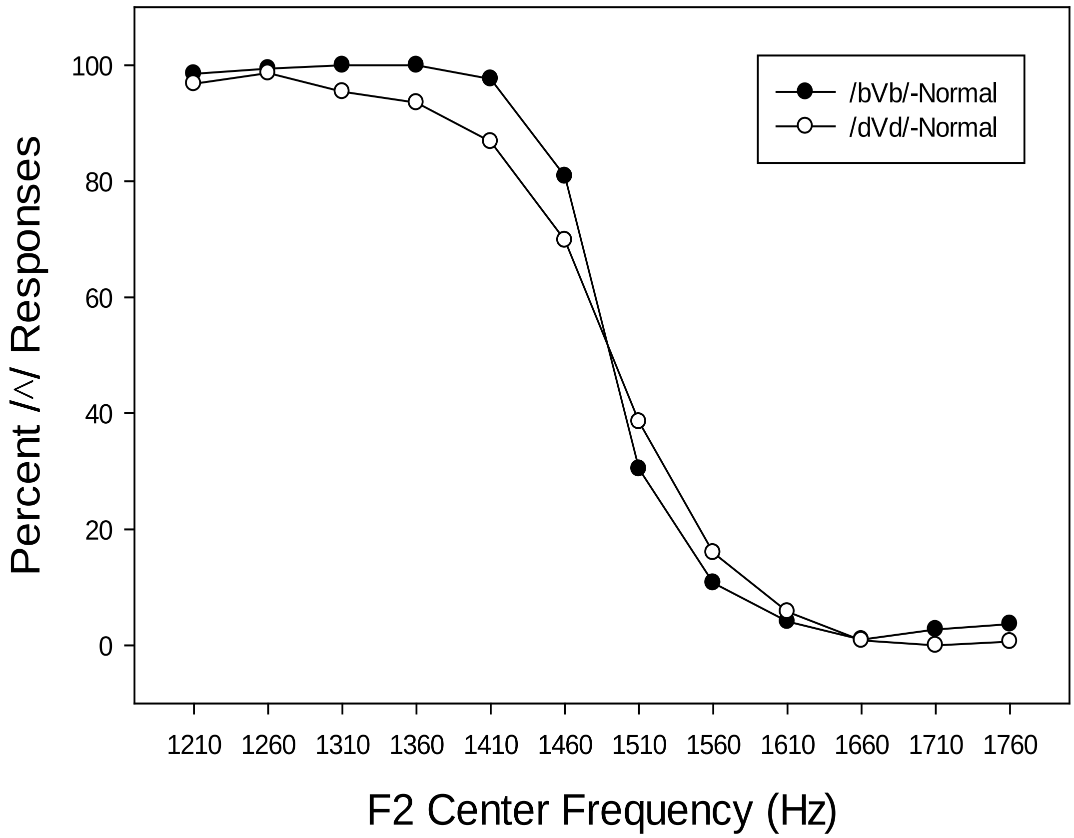

Figure 2. Mean Percent Identification of /ʌ/ in /bVb/ and /dVd/ Syllables, Normal Hearing Condition

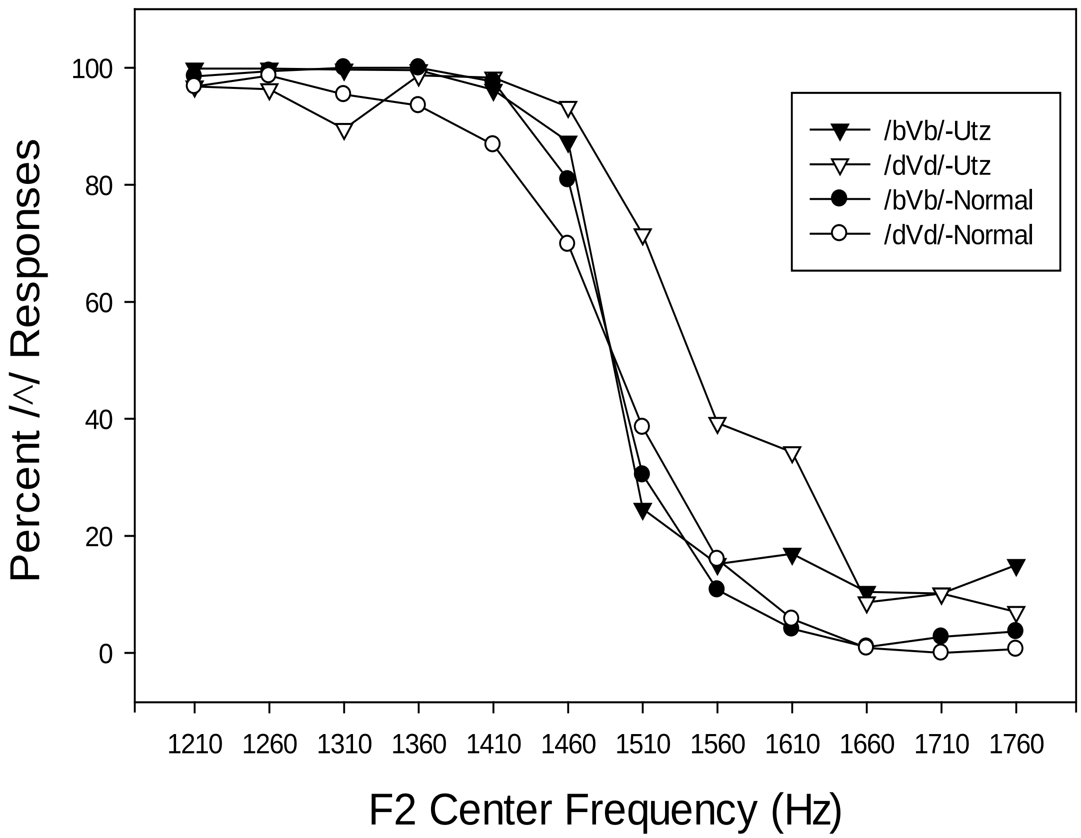

Figure 3. Comparison of Normal Hearing Data to those of Utz (2009)

In the mild and severe hearing loss conditions, it was expected for the context effect to be minimized or absent. In the mild hearing loss condition, the boundary for the /dVd/ context was slightly lower (unexpectedly) than for the /bVb/ condition, although it did not reach significance (Figure 4). In the severe hearing loss condition, however, the boundary was significantly higher for the /dVd/ than the /bVb/ context (Figure 5) suggesting an unexpected context effect.

All of the hearing conditions can be compared in Figure 6. It is clear that the identification functions are highly repeatable for the /bVb/ contexts despite substantive differences in signal integrity. However, the functions for the /dVd/ conditions were much less systematic with regard to location but to a lesser extent shape in that they all signified the presence of distinct vowel categories.

Although there were no context effects observed for the normal hearing condition, 9 of the 17 participants did demonstrate a context effect; 7 out of 17 in the mild hearing loss condition and 11 out of 17 in the severe hearing loss condition. The participants who showed an effect in the normal condition also tended to show an effect in the other hearing loss conditions. All of the participants showed similar performance on the vowels in isolation, so their basic vowel categories likely did not contribute to some showing the effect and others not.

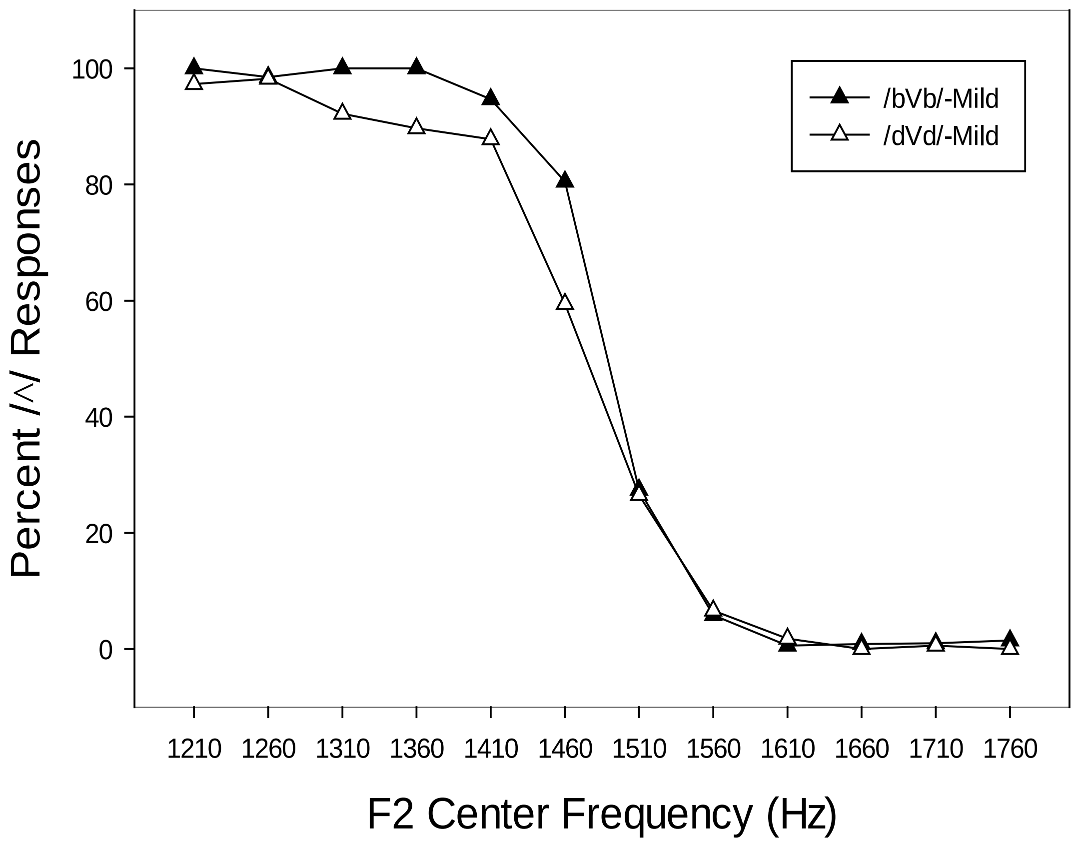

Figure 4. Mean Percent Identification of /ʌ/ in /bVb/ and /dVd/ Syllables, Mild Simulated Hearing Condition

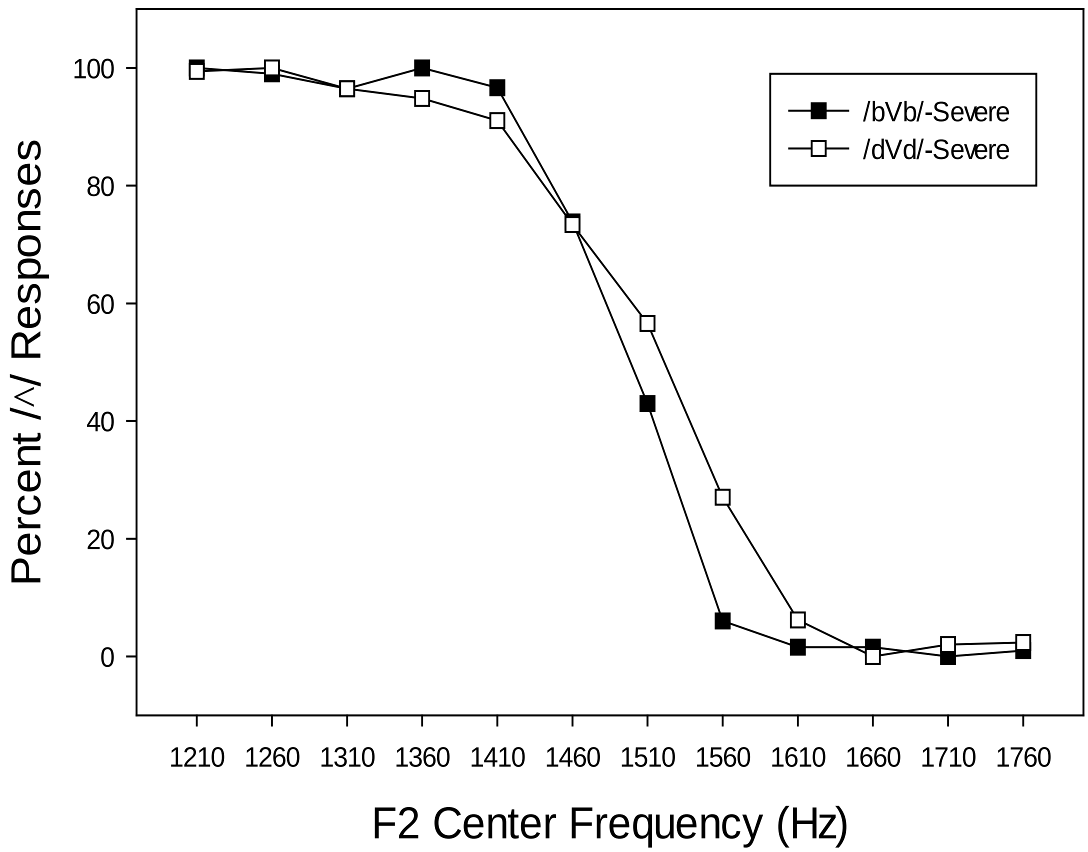

Figure 5. Mean Percent Identification of /ʌ/ in /bVb/ and /dVd/ Syllables, Severe Simulated Hearing Condition

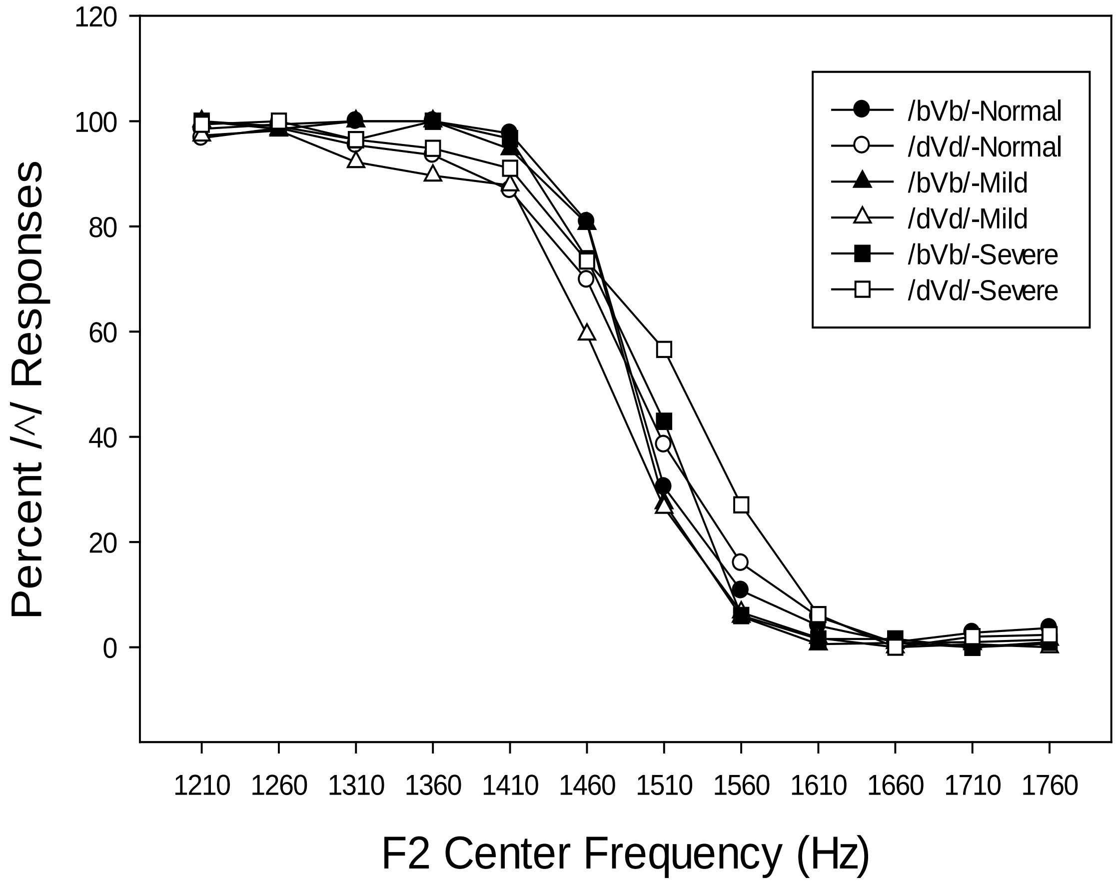

Figure 6. Mean Percent Identification of /ʌ/ in /bVb/ and /dVd/ Syllables, All Hearing Conditions

6.0 DISCUSSION

Contrary to anticipated results, the boundary locations for the vowels remained constant across the /bVb/ and /dVd/ contexts in the normal hearing stimuli on average. Therefore, a phonetic context was not established for the group, although it was observed in some participants. This absence of a phonetic context effect conflicts with the results from the Holt et al. (2000) and Utz (2009) studies. It is important to note that this effect is fragile and other factors could have diminished or interfered with it. For instance, Utz's research design (2009) had to be modified in the middle of the study because her adult group also was not exhibiting a context effect (or exhibiting the opposite effect), although her child group did. The only observable difference between the two groups was the implementation of forced breaks between experimental blocks in the child group, so Utz concluded that an absence of breaks between the different contexts in her adult group might have created interference. When Utz modified her procedures to include forced breaks for a second adult group, the phonetic context effect was then observed.

Although the breaks in the Utz (2009) study improved results, the inclusion of breaks and type of breaks remains an issue for consideration. All of the participants were given mandatory breaks between experimental blocks in this study, but it is possible that the length or nature of these breaks were not sufficient to prevent interference.

Another possibility is that the training procedures or the initial testing with isolated vowels may have established perceptual anchors or a categorical structure that interfered with the effect for some participants. A third explanation is that equating the sound files for average RMS may have introduced an intensity cue that was incompatible with the spectral contrast targeted in the study or that it compromised the contrast itself. It did not, however, interfere with intelligibility or vowel identity because the functions were well-formed and there were clear categories and boundaries. In any case, the lack of a context effect in the normal hearing condition is problematic for interpretation of the effects of hearing loss on phonetic context.

Complicating the lack of an effect for the normal hearing and mild hearing loss conditions (and a tendency to shift in the opposite direction), was that the vowel identification boundaries in the severe hearing loss condition were higher in the /dVd/ context than in the /bVb/ context. This result was especially curious considering that a phonetic context effect was initially predicted to deteriorate in the presence of a simulated hearing loss and the stimuli were indeed very distorted and noisy. It could be that the hearing loss simulation or amplification process introduced cues or contrasts that could be used by the participants as contextual information. If present, these cues may have been audible even in the higher frequency range due to the use of simulated amplification. It also is possible that by making the stimuli more difficult or more ambiguous the listeners were more apt to use the spectral contrastive information available.

7.0 SUMMARY AND CONCLUSIONS

Overall, the effects of context in this study were very different than expected. In the normal hearing condition, a phonetic context effect was not present when expected. Although not significant, the pattern observed for the mild group was in the opposite direction than was expected, and contrary to expectations a context effect was found for the severe hearing loss group. Several factors may have interfered with the effect but it is important to be aware of the fragility of the effect. This study could be improved in the future by modifying the design to change or eliminate the training procedures, include longer breaks and/or include specific tasks to complete during breaks. The simulated hearing loss stimuli also could be altered to try to eliminate or control for acoustic cues that might provide interference with the effect in question. It also would be important to assess the simulated hearing losses with and without recovered audibility.

APPENDIX

BACKGROUND QUESTIONNAIRE

Participant Information Form – Adult Subjects

Subject #: ______________________________

Age: ______________________________

Gender: ______________________________

Race: ______________________________

Education level: ______________________________

Do you have a history of middle ear infections?

____

Have you ever been diagnosed with a hearing loss? If yes, please specify.

____

____

Have you ever been diagnosed with a speech or language disorder? If yes, please specify.

____

____

Do you have a history of any other relevant medical conditions? If yes, please specify.

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