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Acoustic Correlates of Lexical Stress in Central Minnesota English

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ACOUSTIC CORRELATES OF LEXICAL STRESS IN CENTRAL MINNESOTA ENGLISH

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ABSTRACT

In 1958, Fry published a very influential paper detailing the interaction between F0, duration, and intensity in the perception of lexical stress. His main finding was that that hearers of American English rely more on F0 than on the other correlates in the perception of lexical stress. He ranked these three correlates as follows: F0 > Duration > Intensity. However, subsequent research by other phoneticians has yielded a variety of rankings: F0 > Intensity > Duration, Duration > Intensity > F0, Intensity > F0 > Duration, Intensity > Duration > F0, etc. The goal of this paper is to investigate how speakers of Central Minnesota English encode and rank the three acoustic correlates of stress. Ten speakers (five female and five male) produced a total of 1080 tokens (18 words x 2 syllables x 10 participants x 3 correlates). Our findings indicate that the gender of the speaker plays a more prominent role in the production of lexical stress than previously expected.

1.0 Introduction

Fry, a British phonetician, used the research facilities at the Bell Laboratories to conduct two seminal acoustic phonetic experiments on the perception of lexical stress by speakers of American English. In the first experiment (1955), he studied the role of duration and intensity on the perception of lexical stress. Three years later, he replicated his own study by adding a third correlate, namely F0/pitch. His main finding, the one that cemented his legacy in the acoustic phonetic world, is that speakers of American English perceive the correlates of lexical stress hierarchically as follows: F0 > Duration > Intensity. We replicate Fry's study in order to find out how the speakers of Central Minnesota English (CMNE) encode the acoustic correlates of lexical stress when they produce homographic words. The tests items are disyllabic words that are structurally similar but not identical to the ones that Fry used in his experimental studies. We chronicle our procedures, methodology, and findings in five main sections of the paper. The first introduces the participants and the methodology. It is followed by a succinct review of the literature. Thereafter, we focus on each one of the three acoustic correlates of lexical stress. Finally, we summarize our main findings and call for broadening the scope of this study to other parts of Minnesota and to other groups of participants.

2.0 Participants, Data Set, Equipment, and Methodology

Ten participants, five females (FM) and five males (M), participated in this study. The relevant pieces of information about them are provided in Table 1:

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[1] **Authorship responsibilities:** The first author assigned this project to the second author who conducted the research to fulfill the requirements of her BA in Linguistics. They met weekly to discuss her progress. The second author presented her preliminary findings in two venues: at the Minnesota Undergraduates Linguistic Symposium (MULS 2016) and the St. Cloud State University's Student Research Colloquium. She is listed as the second author of this paper to the extent that she did all the measurements, the spectrographs, the acoustic vowel spaces, and provided all the background information on the participants. The first author has redone several measurements and written the paper in light of these new measurements. The paper in its current form and format is significantly different from the one that the second author wrote for her capstone project. The first author, therefore, assumes full responsibility for the content of this paper for any erroneous measurements or interpretations of the acoustic data.

Participant	Age	Birthplace	Current Place of Residence	Years Lived in Central MN
FM1	21	Circle Pines, MN	St. Cloud, MN	17
FM2	18	Duluth, MN	St. Cloud, MN	16.5
FM3	24	Circle Pines, MN	St. Cloud, MN	16.5
FM4	21	Billings, MT	St. Cloud, MN	10
FM5	24	Willmar, MN	St. Cloud, MN	17
M1	20	Vancouver, WA	St. Cloud, MN	18
M2	21	St. Cloud, MN	St. Cloud, MN	21
M3	18	Eden Valley, MN	Albany, MN	18
M4	19	Clearwater, MN	Holdingford, MN	19
M5	22	Shakopee, MN	St. Cloud, MN	20

Table 1: Sociometric Information

The participants were all college-aged females and males from Central Minnesota. Though two of them were born outside of the state of Minnesota, they have lived in Central Minnesota nearly all of their lives and consider themselves speakers of CMNE. Their mean age is 20.8 years, and their length of residency in St. Cloud and the surrounding areas is 17.3 years. The participants are, according to Hazan (2017, p. 36), ideal candidates for acoustic phonetic research of this type because they are in the prime of their linguistic lives and also because they are college-aged students unencumbered with full-time work and family responsibilities. The participants read the following sentences:

1. *The farm used to produce produce.*
2. *The dump was so full that it had to refuse more refuse.*
3. *I had to subject the subject to a series of tests.*
4. *The soldier decided to desert his dessert in the desert.*
5. *Since there was no time like the present, he thought it was time to present the present.*
6. *The judge was forced to convict the convict.*
7. *We will permit her to get a permit.*
8. *I can now project new project results.*

The sentences contain 18 homographic pairs or triplets. All the words are disyllabic; that is, they comprise syllables. Each participant produced a total of 36 syllables. The female participants produced 180 syllables (36 x 5), and so did their male counterparts. The ten participants produced a total of 360 syllables. Since the investigation takes into account three acoustic correlates of stress (F0, intensity, and duration), the total size of the data set under consideration in this paper is 1080 tokens; that is, 360 x 3.

The participants were instructed to read the above-mentioned sentences as naturally as possible. Prior to the recording, they all signed an informed consent form approved by the Institutional Review Board (IRB) at St. Cloud State University. They were recorded wearing a Logitech USB H390 headset mounted with a noise-cancelling microphone on a Dell (XPS) laptop computer with an Intel Core 15. Their data were saved as WAV files and were analyzed acoustically using Praat (Boersma & Weenink, 2017). The recordings took place in quiet settings, not in soundproof rooms.

The spectrographs in Figures 1 and 2 show the methodology that was used in annotating all the files. First, boundaries were drawn around each word. Secondly, within each word, boundaries were set around the nucleus (vowel) of the syllable. Thirdly, each vowel was transcribed phonetically and measured for mean F0, duration, and intensity. The examples below show the spectrographs of Male 2 and Female 3 and illustrate the methodology that was used:

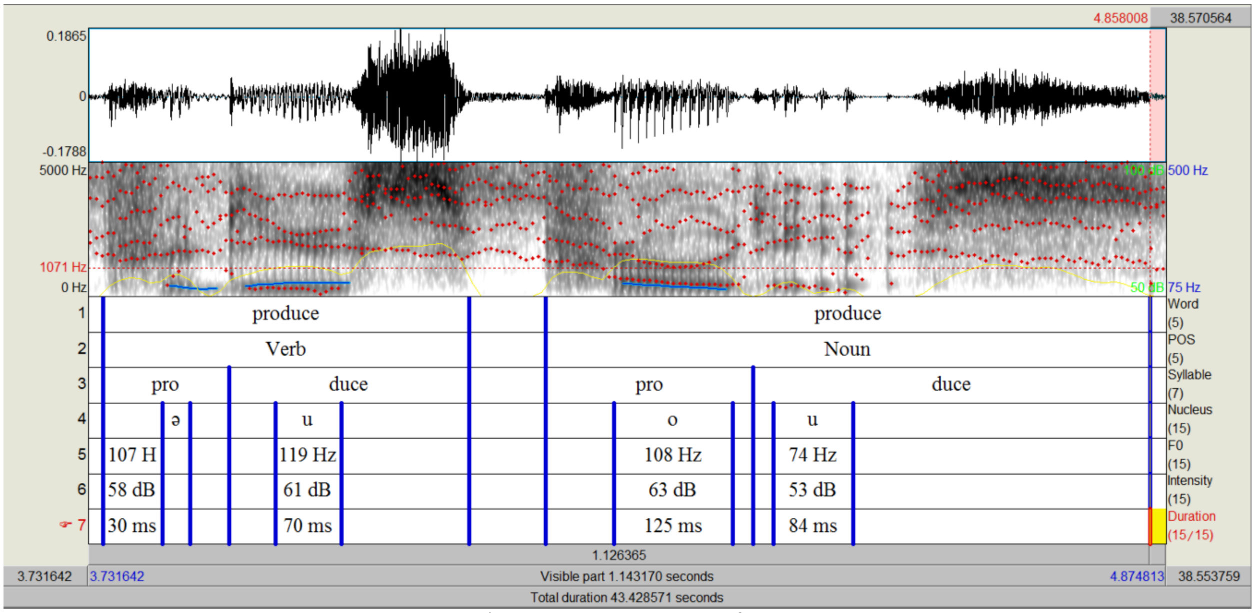

Figure 1: Spectrogram of M2

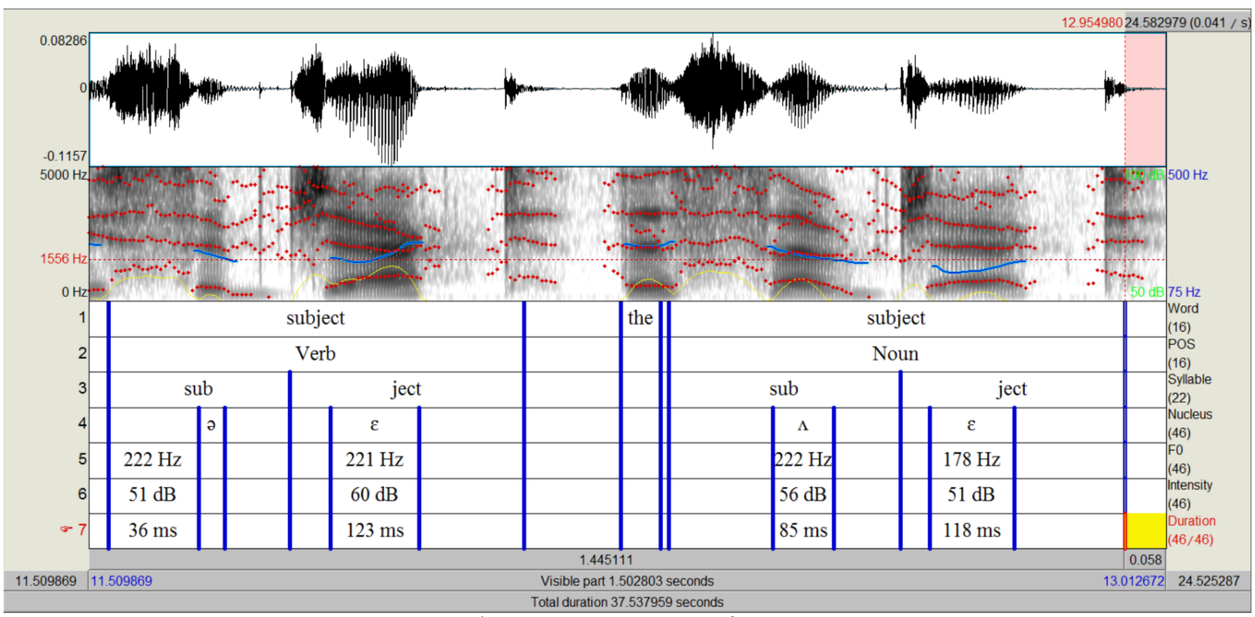

Figure 2: Spectrogram of FM3

The data generated in this study is enormous. It can be used in a variety of ways such as comparing and constrating the acoustic correlates of lexical stress by parts of speech (nouns versus verbs) or by gender (female vs. female, or male versus male, or female versus male). However, since the goal of this study is to replicate Fry's original study, we will concentrate primarily on the ranking of the acoustic correlates of lexical stress. Nevertheless, interspeaker and intraspeaker variations will be discussed when warranted, especially when they deal with gender differences.

3.0 A Succinct Literature Review

Fry's ranking of the acoustic correlates of lexical stress has been controversial from the beginning. A year or so after his 1958 paper, Lieberman (1960, p. 399) conducted a replication study but came up with a different ranking. Instead of F0 > Duration > Intensity as proposed by Fry, Liberman came up with F0 > Intensity > Duration. Morton and Jassem (1965) replicated Fry's study using the nonsense words <soso>, <sasa>, and <sisi> to gauge listeners' perceptions of the acoustic correlates of stress. They found that "fundamental frequency changes were by far the most effective" in helping listeners differentiate between stressed and unstressed syllables (Morton & Jassem, 1965, p. 178). However, they did not comment on any hierarchical relationship between duration and intensity. McClean and Tiffany (1973) also did a similar study and found that higher intensity was correlated with stressed syllables in 99% of the cases, while F0 was higher for stressed syllables in 95% of the cases, and a longer duration was found in 94% of the cases (McClean & Tiffany, 1973, p. 286). In other words, the correlates ranked as follows: Intensity > F0 > Duration. In 1995, Sereno and Jongman conducted a similar study and arrived at the following conclusion: "a stressed syllable has a longer duration, greater amplitude, and higher fundamental frequency than its unstressed counterpart" (Sereno & Jongman, 1995, p. 68). The ranking derived from their study is this: Duration > Intensity > F0, or alternatively Duration = Intensity > F0, where "=" indicates that two correlates contribute equally to the perception of lexical stress. The ranking of Duration = Intensity > F0 is based on this statement that they made on page 71 of their paper: "duration and amplitude appear to be the most robust cues" used in the judgment of stress. In a 2005 article, Kochanski et al. conducted a study on the acoustic correlates of stress in British English and arrived at the following ranking: Intensity > Duration > F0 (pp. 1046, 1052). They published their article under the provocative title of *"Loudness Predicts Prominence: Fundamental Frequency Lends Little."* Several other studies reviewed by Keyworth (2014, pp. 24-28) show that a variety of rankings have been proposed. To the best of our knowledge, no ranking of the acoustic correlates of stress has been made based on CMNE. Our study seeks to fill in the paucity of data in this regard.

3.1 Template Model

The aforementioned review of the literature has shown that there is no consensus on the ranking of the acoustic correlates of lexical stress. The majority of these studies have relied on statistical instruments to arrive at their ranking decisions. However, we will use a different instrument called the "template model." Rabiner (1998, p. 1267) notes that it is well suited for automatic speech recognition by computers. If it works for machine recognition of speech, it can assuredly account for humans' perception of lexical stress. Rabiner provides the following explanation for how the template model works:

> The basic speech recognition pattern can be represented either as a template model or a statistical model. The template is created by averaging spectral vectors of the different training tokens, from which the pattern is created, along the time alignment path provided by the dynamic time warping procedure. Hence the template model provides very fine temporal

resolutions (typically 10-15 ms) but only provides first-order statistics (mean values) of the spectral parameters of the reference.

The model can be adapted and applied to human speech recognition very easily. All that is required is to substitute the "spectral vectors" with Just Noticeable Difference (JND) thresholds in F0, duration, and intensity. The model does not call for a sophisticated statistical machinery. All that one needs to do is to provide first-order statistical calculations, i.e., the mean of the various values. We have done so for all the tables in the upcoming sections. We have additionally included calculations for standard deviations even though they are not required when using the template model.

4.0 Analysis of F0 Data

F0, also known as fundamental frequency or pitch, measures the vibrations that take place in the glottis when speech is produced. With regard to lexical stress, Fry (1958, p. 142) noted that "a higher pitch produces an impression of greater stress." Various experimental studies have found that the human ear is very sensitive to minute variations in pitch, as low as 0.30% according to Young (2011, p. 609). However, in non-laboratory settings, and also to make calculation easier, the threshold for the JND in F0 has been set at ≥ 1 Hz (Lehiste, 1976, p. 230). This means that in disyllabic or multisyllabic words, a syllable is deemed stressed or strong if, and only if, its nucleus is ≥ 1 Hz higher than the nuclei of all other syllables in the same word. With this threshold in mind, let us examine the words in the tables below to determine which syllables are stressed and which ones are not.

Words	**proDUCE, V**		**PROduce, N**		**reFUSE, V**		**REfuse, N**	
F0	**V1**	**V2**	**V1**	**V2**	**V1**	**V2**	**V1**	**V2**
FM1	222 Hz	203 Hz	176 Hz	125 Hz	192 Hz	235 Hz	154 Hz	103 Hz
FM2	211 Hz	188 Hz	178 Hz	107 Hz	192 Hz	188 Hz	171 Hz	78 Hz
FM3	205 Hz	205 Hz	183 Hz	152 Hz	198 Hz	225 Hz	180 Hz	146 Hz
FM4	187 Hz	187 Hz	155 Hz	78 Hz	215 Hz	74 Hz	74 Hz	74 Hz
FM5	196 Hz	217 Hz	194 Hz	81 Hz	180 Hz	198 Hz	170 Hz	91 Hz
FM Mean	**204 Hz**	**200 Hz**	**177 Hz**	**109 Hz**	**195 Hz**	**184 Hz**	**150 Hz**	**98 Hz**
FM St. Dev	**13.48**	**12.61**	**14.24**	**31.04**	**12.76**	**64.41**	**43.40**	**28.95**
M1	111 Hz	150 Hz	124 Hz	74 Hz	100 Hz	186 Hz	157 Hz	74 Hz
M2	107 Hz	119 Hz	108 Hz	74 Hz	107 Hz	110 Hz	107 Hz	74 Hz
M3	117 Hz	135 Hz	115 Hz	129 Hz	103 Hz	129 Hz	112 Hz	74 Hz
M4	121 Hz	114 Hz	115 Hz	74 Hz	109 Hz	112 Hz	113 Hz	74 Hz
M5	97 Hz	102 Hz	90 Hz	74 Hz	85 Hz	117 Hz	75 Hz	74 Hz
M Mean	**111 Hz**	**124 Hz**	**110 Hz**	**85 Hz**	**101 Hz**	**131 Hz**	**113 Hz**	**74 Hz**
M St. Dev	**9.32**	**18.75**	**12.74**	**26.62**	**9.50**	**31.73**	**29.23**	**NA**

Table 2A: F0 Results[2]

[2] Ideally, it would have been preferable to have one table containing all the words. In spite of many attempts, the font sizes would have had to be reduced to the point of needing a magnifying glass to read the data. An unsatisfying yet easily readable compromise was found, namely to display most words according to their homographic pairs or triplets. This has resulted into five tables per correlate.

Words	**subJECT, V**		**SUBject, N**		**deSERT, V**		**deSSERT, N**	
F0	**V1**	**V2**	**V1**	**V2**	**V1**	**V2**	**V1**	**V2**
FM1	235 Hz	242 Hz	257 Hz	82 Hz	206 Hz	220 Hz	211 Hz	183 Hz
FM2	220 Hz	201 Hz	189 Hz	74 Hz	184 Hz	192 Hz	206 Hz	176 Hz
FM3	222 Hz	221 Hz	222 Hz	178 Hz	199 Hz	217 Hz	289 Hz	168 Hz
FM4	180 Hz	162 Hz	173 Hz	81 Hz	85 Hz	180 Hz	171 Hz	181 Hz
FM5	228 Hz	242 Hz	214 Hz	169 Hz	182 Hz	222 Hz	199 Hz	198 Hz
FM Mean	**217 Hz**	**214 Hz**	**211 Hz**	**117 Hz**	**171 Hz**	**206 Hz**	**215 Hz**	**181 Hz**
FM St. Dev	**21.49**	**33.50**	**32.30**	**51.95**	**49.23**	**19.01**	**44.06**	**11.03**
M1	74 Hz	182 Hz	185 Hz	81 Hz	92 Hz	164 Hz	106 Hz	118 Hz
M2	104 Hz	119 Hz	124 Hz	78 Hz	102 Hz	137 Hz	103 Hz	92 Hz
M3	117 Hz	154 Hz	130 Hz	78 Hz	74 Hz	124 Hz	74 Hz	104 Hz
M4	117 Hz	129 Hz	117 Hz	74 Hz	107 Hz	127 Hz	123 Hz	104 Hz
M5	93 Hz	74 Hz	132 Hz	131 Hz	92 Hz	115 Hz	103 Hz	106 Hz
M Mean	**101 Hz**	**132 Hz**	**138 Hz**	**88 Hz**	**93 Hz**	**133 Hz**	**102 Hz**	**105 Hz**
M St. Dev	**18.12**	**40.39**	**27.13**	**23.91**	**12.64**	**18.82**	**17.63**	**9.23**

Table 2B: F0 Results

Words	**DEsert, N**		**PREsent, N**		**preSENT, V**		**PREsent, N**	
F0	**V1**	**V2**	**V1**	**V2**	**V1**	**V2**	**V1**	**V2**
FM1	131 Hz	74 Hz	247 Hz	89 Hz	217 Hz	196 Hz	168 Hz	74 Hz
FM2	93 Hz	74 Hz	175 Hz	168 Hz	188 Hz	178 Hz	174 Hz	94 Hz
FM3	170 Hz	132 Hz	187 Hz	155 Hz	242 Hz	166 Hz	301 Hz	181 Hz
FM4	74 Hz	74 Hz	173 Hz	74 Hz	178 Hz	173 Hz	74 Hz	74 Hz
FM5	215 Hz	151 Hz	225 Hz	166 Hz	184 Hz	184 Hz	180 Hz	122 Hz
FM Mean	**137 Hz**	**101 Hz**	**201 Hz**	**130 Hz**	**202 Hz**	**179 Hz**	**179 Hz**	**109 Hz**
FM St. Dev	**57.26**	**37.58**	**32.97**	**45.22**	**27.02**	**11.39**	**80.71**	**44.80**
M1	111 Hz	74 Hz	129 Hz	83 Hz	112 Hz	108 Hz	175 Hz	74 Hz
M2	95 Hz	74 Hz	127 Hz	74 Hz	107 Hz	98 Hz	97 Hz	74 Hz
M3	104 Hz	74 Hz	113 Hz	74 Hz	100 Hz	102 Hz	89 Hz	74 Hz
M4	83 Hz	81 Hz	119 Hz	97 Hz	114 Hz	123 Hz	74 Hz	74 Hz
M5	90 Hz	91 Hz	121 Hz	126 Hz	91 Hz	115 Hz	74 Hz	74 Hz
M Mean	**97 Hz**	**78 Hz**	**122 Hz**	**90 Hz**	**105 Hz**	**109 Hz**	**102 Hz**	**74 Hz**
M St. Dev.	**11.10**	**16.72**	**6.42**	**24.77**	**9.42**	**10.03**	**42.10**	**0**

Table 2C: F0 Results

Words	**conVICT, V**		**CONvict, N**		**perMIT, V**		**PERmit, N**	
F0	**V1**	**V2**	**V1**	**V2**	**V1**	**V2**	**V1**	**V2**
FM1	219 Hz	197 Hz	187 Hz	74 Hz	243 Hz	297 Hz	200 Hz	74 Hz
FM2	214 Hz	180 Hz	177 Hz	74 Hz	228 Hz	226 Hz	180 Hz	97 Hz
FM3	207 Hz	221 Hz	176 Hz	173 Hz	265 Hz	269 Hz	190 Hz	134 Hz
FM4	184 Hz	187 Hz	137 Hz	74 Hz	178 Hz	204 Hz	110 Hz	74 Hz
FM5	189 Hz	194 Hz	181 Hz	100 Hz	203 Hz	211 Hz	182 Hz	74 Hz
FM Mean	**203 Hz**	**196 Hz**	**172 Hz**	**99 Hz**	**223 Hz**	**241 Hz**	**172 Hz**	**91 Hz**

FM St. Dev	**15.40**	**15.55**	**19.82**	**42.87**	**33.96**	**40.04**	**35.76**	**26.23**
M1	92 Hz	74 Hz	96 Hz	85 Hz	148 Hz	135 Hz	96 Hz	74 Hz
M2	108 Hz	117 Hz	100 Hz	74 Hz	121 Hz	155 Hz	118 Hz	93 Hz
M3	107 Hz	104 Hz	102 Hz	74 Hz	117 Hz	145 Hz	101 Hz	74 Hz
M4	74 Hz	123 Hz	74 Hz	74 Hz	124 Hz	126 Hz	122 Hz	74 Hz
M5	105 Hz	129 Hz	142 Hz	128 Hz	105 Hz	131 Hz	101 Hz	83 Hz
M Mean	**97 Hz**	**109 Hz**	**103 Hz**	**87 Hz**	**123 Hz**	**138 Hz**	**108 Hz**	**80 Hz**
M St. Dev.	**14.48**	**21.85**	**24.60**	**20.93**	**15.73**	**11.61**	**11.59**	**8.45**

Table 2D: F0 Results

Words	**proJECT, V**		**PROject, N**	
F0	**V1**	**V2**	**V1**	**V2**
FM1	257 Hz	204 Hz	198 Hz	74 Hz
FM2	232 Hz	183 Hz	172 Hz	180 Hz
FM3	318 Hz	197 Hz	192 Hz	164 Hz
FM4	211 Hz	74 Hz	117 Hz	74 Hz
FM5	239 Hz	188 Hz	180 Hz	172 Hz
FM Mean	**251 Hz**	**169 Hz**	**172 Hz**	**133 Hz**
FM St. Dev	**40.71**	**53.83**	**32.27**	**53.97**
M1	74 Hz	136 Hz	127 Hz	125 Hz
M2	120 Hz	113 Hz	106 Hz	74 Hz
M3	117 Hz	122 Hz	115 Hz	74 Hz
M4	111 Hz	115 Hz	118 Hz	88 Hz
M5	74 Hz	98 Hz	74 Hz	74 Hz
M Mean	**99 Hz**	**117 Hz**	**108 Hz**	**87 Hz**
M St. Dev.	**23.23**	**13.85**	**20.43**	**22.09**

Table 2E: F0 Results

There are numerous instances when the F0 of the nucleus of the unstressed syllable is "undefined." This does not indicate an absence of vocal fold vibrations, but rather that the vibrations were below the 75 Hz minimum default settings in Praat. No effort was made to change the settings. Instead, all "undefined" F0s were taken to be 74 Hz. This happened at least 19 times in the pronunciations of the female participants, and 21 times in the pronunciations of male participants. The F0s of the "undefined" nuclei amount to 10.52% of the 380 syllables produced by female and male participants.

4.1 F0 in Female and Male Pronunciation

The female participants produced a total of 180 syllables. Since all the words in the data are disyllabic, one would have expected them to produce 90 stressed syllables and 90 unstressed syllables. However, when the JND in F0 is applied to the data, we found that only 53 of the 90 syllables were stressed according to expected phonological rules. In other words, 58.88% of the homographic words were stressed as expected. The female participants' average F0 was 173.32 Hz for all the 180 syllables that they produced. In the males' speech, 73 out of 90 stressed syllables were stressed as expected; that is, 81.11%. Their average F0 was 104.67 Hz. The mean F0s produced by our participants fall within the expected ranges for female and male speakers. According to Stevens (1998:1232), the normal ranges are 170 to 340 Hz for females and 80 to 160

Hz for males. Furthermore, the ratio of female to male F0 in our study is statistically identical with those reported by Peterson and Barney (1952, p. 183) and by Hillenbrand et al. (1995, p. 3103). In our study, the female to male ratio is 59.77%. In Peterson and Barney, it was 60%, and in Hillenbrand et al., it was 59.19%.[3]

5.0 Analysis of Duration Data

Kenstowicz (1994, p. 549) contends that "[lexical] stress is realized through…vowel/ consonant length among other acoustic cues." Duration ranks second in importance in Fry's hierarchy. Numerous psychoacoustic experiments have shown that a segment is perceived as being longer than another segment if the durational distance between them is ≥ 10 ms (Lehiste,1976, p. 226). In other words, the nucleus of the stressed syllable is longer than the nucleus of an unstressed syllable if the former is longer than the latter by ≥ 10 ms or more. This threshold is applied to the data in the tables below to gauge how lexical stress in realized in CMNE:

Words	**proDUCE, V**		**PROduce, N**		**reFUSE, V**		**REfuse, N**	
Duration	**V1**	**V2**	**V1**	**V2**	**V1**	**V2**	**V1**	**V2**
FM1	66 ms	108 ms	108 ms	82 ms	46 ms	154 ms	126 ms	153 ms
FM2	37 ms	131 ms	146 ms	122 ms	90 ms	127 ms	82 ms	89 ms
FM3	75 ms	120 ms	124 ms	130 ms	82 ms	136 ms	102 ms	105 ms
FM4	27 ms	164 ms	114 ms	93 ms	47 ms	159 ms	61 ms	84 ms
FM5	45 ms	174 ms	130 ms	126 ms	81 ms	101 ms	81 ms	126 ms
FM Mean	**50 ms**	**139 ms**	**124 ms**	**111 ms**	**69 ms**	**135 ms**	**90 ms**	**111 ms**
FM St. Dev	**20.02**	**28.44**	**14.79**	**21.63**	**21.02**	**23.22**	**24.62**	**28.45**
M1	82 ms	178 ms	121 ms	73 ms	71 ms	135 ms	67 ms	68 ms
M2	30 ms	70 ms	125 ms	84 ms	64 ms	111 ms	74 ms	96 ms
M3	52 ms	131 ms	101 ms	88 ms	57 ms	107 ms	47 ms	35 ms
M4	79 ms	174 ms	99 ms	91 ms	37 ms	163 ms	81 ms	116 ms
M5	43 ms	136 ms	68 ms	84 ms	65 ms	137 ms	62 ms	89 ms
M Mean	**57 ms**	**138 ms**	**103 ms**	**84 ms**	**59 ms**	**131 ms**	**66 ms**	**81 ms**
M St. Dev.	**22.69**	**43.51**	**22.65**	**6.82**	**13.16**	**22.65**	**12.91**	**30.82**

Table 3A: Duration Results

Words	**subJECT, V**		**SUBject, N**		**deSERT, V**		**deSSERT, N**	
Duration	**V1**	**V2**	**V1**	**V2**	**V1**	**V2**	**V1**	**V2**
FM1	29 ms	113 ms	77 ms	92 ms	89 ms	56 ms	60 ms	119 ms
FM2	28 ms	98 ms	72 ms	86 ms	53 ms	146 ms	52 ms	145 ms
FM3	36 ms	123 ms	85 ms	118 ms	86 ms	148 ms	71 ms	168 ms
FM4	38 ms	159 ms	88 ms	108 ms	64 ms	181 ms	46 ms	116 ms
FM5	88 ms	105 ms	86 ms	124 ms	58 ms	203 ms	49 ms	211 ms
FM Mean	**44 ms**	**120 ms**	**82 ms**	**106 ms**	**70 ms**	**147 ms**	**56 ms**	**152 ms**
FM St. Dev	**25.08**	**23.91**	**6.80**	**16.33**	**16.48**	**56.07**	**10.06**	**39.28**
M1	40 ms	106 ms	71 ms	109 ms	71 ms	169 ms	53 ms	134 ms

[3] The mean F0 measurements in Peterson and Barney are 223 Hz for females and 132 Hz for males. The mean F0 measurements in Hillenbrand et al. are 220 Hz for females and 132 Hz for males. It is customary in acoustic phonetic studies to estimate female F0 values by raising male values by 50%.

M2	41 ms	69 ms	72 ms	76 ms	26 ms	108 ms	37 ms	61 ms
M3	22 ms	97 ms	47 ms	89 ms	47 ms	150 ms	28 ms	197 ms
M4	41 ms	141 ms	95 ms	171 ms	87 ms	163 ms	114 ms	163 ms
M5	15 ms	101 ms	66 ms	81 ms	42 ms	129 ms	40 ms	132 ms
M Mean	**32 ms**	**103 ms**	**70 ms**	**105 ms**	**55 ms**	**144 ms**	**54 ms**	**137 ms**
M St. Dev.	**12.40**	**25.73**	**17.14**	**38.87**	**24.25**	**25.21**	**34.50**	**50.21**

Table 3B: Duration Results

Words	**DEsert, N**		**PREsent, N**		**preSENT, V**		**PREsent, N**	
Duration	**V1**	**V2**	**V1**	**V2**	**V1**	**V2**	**V1**	**V2**
FM1	115 ms	37 ms	83 ms	72 ms	75 ms	106 ms	88 ms	63 ms
FM2	73 ms	116 ms	80 ms	91 ms	58 ms	115 ms	98 ms	81 ms
FM3	93 ms	140 ms	76 ms	70 ms	63 ms	105 ms	77 ms	70 ms
FM4	102 ms	79 ms	48 ms	99 ms	60 ms	72 ms	50 ms	34 ms
FM5	112 ms	135 ms	103 ms	118 ms	37 ms	109 ms	82 ms	65 ms
FM Mean	**99 ms**	**101 ms**	**78 ms**	**90 ms**	**59 ms**	**101 ms**	**79 ms**	**63 ms**
FM St. Dev	**16.93**	**43.25**	**19.74**	**19.94**	**13.76**	**16.89**	**18**	**17.44**
M1	85 ms	36 ms	66 ms	81 ms	61 ms	91 ms	65 ms	63 ms
M2	79 ms	78 ms	61 ms	59 ms	51 ms	93 ms	86 ms	97 ms
M3	84 ms	112 ms	68 ms	79 ms	67 ms	115 ms	69 ms	99 ms
M4	114 ms	120 ms	115 ms	151 ms	60 ms	199 ms	77 ms	112 ms
M5	97 ms	82 ms	59 ms	64 ms	41 ms	107 ms	71 ms	55 ms
M Mean	**92 ms**	**86 ms**	**74 ms**	**87 ms**	**56 ms**	**121 ms**	**74 ms**	**85 ms**
M St. Dev.	**14.06**	**33.21**	**23.32**	**37.11**	**10.15**	**44.72**	**8.17**	**24.76**

Table 3C: Duration Results

Words	**conVICT, V**		**CONvict, N**		**perMIT, V**		**PERmit, N**	
Duration	**V1**	**V2**	**V1**	**V2**	**V1**	**V2**	**V1**	**V2**
FM1	25 ms	78 ms	92 ms	41 ms	33 ms	72 ms	52 ms	94 ms
FM2	42 ms	66 ms	107 ms	58 ms	21 ms	42 ms	61 ms	97 ms
FM3	59 ms	78 ms	102 ms	110 ms	26 ms	84 ms	79 ms	91 ms
FM4	27 ms	105 ms	103 ms	47 ms	22 ms	60 ms	75 ms	45 ms
FM5	63 ms	88 ms	138 ms	142 ms	62 ms	109 ms	93 ms	121 ms
FM Mean	**43 ms**	**83 ms**	**108 ms**	**80 ms**	**33 ms**	**73 ms**	**72 ms**	**90 ms**
FM St. Dev	**17.58**	**14.56**	**17.44**	**44.26**	**16.99**	**25.23**	**15.97**	**27.62**
M1	76 ms	53 ms	82 ms	40 ms	38 ms	70 ms	56 ms	44 ms
M2	91 ms	61 ms	106 ms	86 ms	47 ms	63 ms	80 ms	40 ms
M3	31 ms	96 ms	103 ms	58 ms	33 ms	63 ms	69 ms	69 ms
M4	23 ms	169 ms	135 ms	115 ms	64 ms	189 ms	89 ms	62 ms
M5	72 ms	69 ms	121 ms	86 ms	56 ms	74 ms	74 ms	45 ms
M Mean	**59 ms**	**90 ms**	**109 ms**	**77 ms**	**48 ms**	**92 ms**	**74 ms**	**52 ms**
M St. Dev.	**29.84**	**47.24**	**19.96**	**28.88**	**12.70**	**54.54**	**12.34**	**12.71**

Table 3D: Duration Results

Words	**proJECT, V**		**PROject, N**	
Duration	**V1**	**V2**	**V1**	**V2**
FM1	30 ms	116 ms	117 ms	68 ms
FM2	32 ms	116 ms	105 ms	62 ms
FM3	36 ms	110 ms	114 ms	59 ms
FM4	48 ms	128 ms	132 ms	95 ms
FM5	38 ms	156 ms	144 ms	93 ms
FM Mean	**37 ms**	**125 ms**	**122 ms**	**75 ms**
FM St. Dev	**7.01**	**18.42**	**15.50**	**17.30**
M1	27 ms	101 ms	91 ms	64 ms
M2	48 ms	94 ms	119 ms	81 ms
M3	35 ms	124 ms	110 ms	68 ms
M4	106 ms	182 ms	149 ms	142 ms
M5	22 ms	104 ms	115 ms	60 ms
M Mean	**48 ms**	**121 ms**	**117 ms**	**83 ms**
M St. Dev.	**34.09**	**35.87**	**20.96**	**33.91**

Table 3E: Duration Results

5.1 Duration in Female and Male Pronunciation

The female participants produced 180 syllables, half of which were stressed and another half unstressed. According to the JND in duration, stressed syllables are expected to be at least 10 ms longer than the unstressed ones. The data showed that 55 out of 90 putative stressed syllables met this threshold. In other words, the stressed syllables were longer than the unstressed ones in 61.11% of cases. In the pronunciation of male speakers, it was 66.66%; that is, 60 out of 90 syllables. The duration data lends support to Fry's (1955, p. 765) observation that "duration measurements showed remarkably little variation from speaker to speaker." We see this in the negligible pronunciation difference between the female and male participants. The 5.55% difference in duration between females and males is not statistically significant. The difference is also not perceptually salient. The total duration of the 180 syllables produced by female speakers is 89.39 ms versus 85.42 ms for male speakers. Since the distance of 3.99 ms is below the 10 ms threshold, we conclude that there is perceptually no difference between the female and male speakers in our study as far as duration is concerned. Our data concords with Fry's findings mentioned earlier in this paragraph.[4]

6.0 Analysis of Intensity Data

Strictly speaking, intensity is not synonymous with loudness. However, even in the specialized literature, both are often used interchangeably. The JND in intensity for perceiving that one signal is minimally louder than another has been set by convention at $\geq$ 3dB (Rossing, 2007, p. 472). Accordingly, in a disyllabic or multisyllabic word, the nucleus of the stressed

[4] Hillenbrand et al. (1995, p. 3103) report an average duration of vowels segments of 163 ms between females (294 ms) versus 131 ms for males when vowels are procuded in their citation forms. In Koffi (2017, p. 15) female speakers' vowels in citation form last on average 231 ms versus 214 ms for male speakers. The difference between females and males in CMNE is 17 ms, which is, according to Hirsh (1959, 767) the optimal distance to perceive a duration distance for segments lasting more than 200 ms. This is difference is less considerable compared to the speakers in Hillenbrand et al.'s data. In running speech, the 17 ms difference disappears.

syllable should be at least ≥ 3 dB louder than the nuclei of all other syllables in the same word. Stressed and unstressed nuclei in the tables below are assessed in reference to the ≥ 3 dB threshold.

Words	**proDUCE, V**		**PROduce, N**		**reFUSE, V**		**REfuse, N**	
Intensity	**V1**	**V2**	**V1**	**V2**	**V1**	**V2**	**V1**	**V2**
FM1	56 dB	49 dB	52 dB	46 dB	56 dB	51 dB	56 dB	40 dB
FM2	53 dB	53 dB	58 dB	51 dB	51 dB	51 dB	59 dB	49 dB
FM3	53 dB	50 dB	54 dB	39 dB	51 dB	48 dB	52 dB	38 dB
FM4	60 dB	64 dB	64 dB	57 dB	63 dB	59 dB	67 dB	55 dB
FM5	70 dB	68 dB	73 dB	61 dB	69 dB	65 dB	71 dB	57 dB
FM Mean	**58 dB**	**57 dB**	**60 dB**	**51 dB**	**58 dB**	**55 dB**	**61 dB**	**48 dB**
FM St. Dev	**7.09**	**8.64**	**8.50**	**8.73**	**7.87**	**7.01**	**7.84**	**8.58**
M1	63 dB	64 dB	70 dB	60 dB	64 dB	59 dB	64 dB	54 dB
M2	58 dB	61 dB	63 dB	53 dB	60 dB	58 dB	63 dB	53 dB
M3	65 dB	61 dB	63 dB	54 dB	56 dB	55 dB	60 dB	48 dB
M4	65 dB	65 dB	69 dB	56 dB	63 dB	64 dB	65 dB	55 dB
M5	63 dB	64 dB	68 dB	60 dB	64 dB	61 dB	67 dB	56 dB
M Mean	**63 dB**	**63 dB**	**67 dB**	**57 dB**	**61 dB**	**59 dB**	**64 dB**	**53 dB**
M St. Dev.	**2.86**	**1.87**	**3.36**	**3.29**	**3.44**	**3.36**	**2.59**	**3.11**

Table 3A: Intensity Results

Words	**subJECT, V**		**SUBject, N**		**deSERT, V**		**deSSERT, N**	
Intensity	**V1**	**V2**	**V1**	**V2**	**V1**	**V2**	**V1**	**V2**
FM1	53 dB	63 dB	65 dB	54 dB	50 dB	60 dB	53 dB	62 dB
FM2	59 dB	64 dB	62 dB	57 dB	54 dB	60 dB	57 dB	59 dB
FM3	51 dB	60 dB	56 dB	51 dB	51 dB	56 dB	53 dB	51 dB
FM4	63 dB	74 dB	74 dB	65 dB	63 dB	72 dB	60 dB	69 dB
FM5	78 dB	78 dB	76 dB	74 dB	69 dB	75 dB	67 dB	78 dB
FM Mean	**61 dB**	**68 dB**	**67 dB**	**60 dB**	**57 dB**	**65 dB**	**58 dB**	**64 dB**
FM St. Dev	**10.73**	**7.76**	**8.35**	**9.31**	**8.26**	**8.35**	**5.83**	**10.23**
M1	68 dB	69 dB	74 dB	66 dB	65 dB	71 dB	71 dB	72 dB
M2	64 dB	69 dB	67 dB	60 dB	59 dB	66 dB	60 dB	62 dB
M3	58 dB	65 dB	68 dB	60 dB	59 dB	63 dB	68 dB	62 dB
M4	65 dB	75 dB	73 dB	71 dB	65 dB	71 dB	76 dB	66 dB
M5	59 dB	69 dB	72 dB	63 dB	70 dB	74 dB	72 dB	75 dB
M Mean	**63 dB**	**69 dB**	**71 dB**	**64 dB**	**64 dB**	**69 dB**	**69 dB**	**67 dB**
M St. Dev.	**4.21**	**3.58**	**3.11**	**4.64**	**4.67**	**4.42**	**5.98**	**5.90**

Table 3B: Intensity Results

Words	**DEsert, N**		**PREsent, N**		**preSENT, V**		**PREsent, N**	
Intensity	**V1**	**V2**	**V1**	**V2**	**V1**	**V2**	**V1**	**V2**
FM1	55 dB	51 dB	62 dB	49 dB	49 dB	58 dB	51 dB	46 dB
FM2	59 dB	55 dB	59 dB	52 dB	51 dB	58 dB	59 dB	48 dB
FM3	50 dB	47 dB	54 dB	44 dB	50 dB	48 dB	53 dB	41 dB
FM4	67 dB	56 dB	72 dB	57 dB	68 dB	69 dB	63 dB	57 dB

FM5	83 dB	69 dB	77 dB	70 dB	64 dB	76 dB	72 dB	63 dB
FM Mean	**63 dB**	**56 dB**	**65 dB**	**54 dB**	**56 dB**	**62 dB**	**60 dB**	**51 dB**
FM St. Dev	**12.89**	**8.29**	**9.47**	**9.91**	**8.91**	**10.87**	**8.41**	**8.86**
M1	71 dB	53 dB	73 dB	54 dB	65 dB	70 dB	71 dB	50 dB
M2	60 dB	47 dB	68 dB	54 dB	62 dB	63 dB	59 dB	47 dB
M3	64 dB	51 dB	62 dB	48 dB	60 dB	64 dB	60 dB	49 dB
M4	66 dB	56 dB	75 dB	62 dB	64 dB	69 dB	65 dB	58 dB
M5	73 dB	64 dB	77 dB	69 dB	67 dB	70 dB	66 dB	60 dB
M Mean	**67 dB**	**54 dB**	**71 dB**	**57 dB**	**64 dB**	**67 dB**	**64 dB**	**53 dB**
M St. Dev.	**5.26**	**6.38**	**6.04**	**8.17**	**2.70**	**3.42**	**4.87**	**5.81**

Table 3C: Intensity Results

Words	**conVICT, V**		**CONvict, N**		**perMIT, V**		**PERmit, N**	
Intensity	**V1**	**V2**	**V1**	**V2**	**V1**	**V2**	**V1**	**V2**
FM1	50 dB	58 dB	51 dB	50 dB	58 dB	60 dB	50 dB	49 dB
FM2	58 dB	62 dB	58 dB	53 dB	56 dB	63 dB	55 dB	47 dB
FM3	50 dB	55 dB	55 dB	49 dB	54 dB	59 dB	50 dB	46 dB
FM4	60 dB	66 dB	65 dB	59 dB	65 dB	75 dB	62 dB	59 dB
FM5	65 dB	75 dB	76 dB	68 dB	71 dB	77 dB	70 dB	65 dB
FM Mean	**57 dB**	**63 dB**	**61 dB**	**56 dB**	**61 dB**	**67 dB**	**57 dB**	**53 dB**
FM St. Dev	**6.54**	**7.79**	**9.82**	**7.85**	**7.05**	**8.56**	**8.59**	**8.38**
M1	58 dB	72 dB	68 dB	57 dB	64 dB	72 dB	68 dB	50 dB
M2	63 dB	65 dB	62 dB	56 dB	67 dB	67 dB	64 dB	58 dB
M3	65 dB	65 dB	64 dB	57 dB	62 dB	64 dB	63 dB	50 dB
M4	64 dB	74 dB	67 dB	61 dB	68 dB	68 dB	70 dB	64 dB
M5	64 dB	71 dB	71 dB	63 dB	68 dB	67 dB	71 dB	58 dB
M Mean	**63 dB**	**69 dB**	**66 dB**	**59 dB**	**66 dB**	**68 dB**	**67 dB**	**56 dB**
M St. Dev.	**2.77**	**4.16**	**3.51**	**3.03**	**2.68**	**2.88**	**3.56**	**6**

Table 3D: Intensity Results

Words	**proJECT, V**		**PROject, N**	
Intensity	**V1**	**V2**	**V1**	**V2**
FM1	55 dB	62 dB	58 dB	60 dB
FM2	56 dB	64 dB	61 dB	50 dB
FM3	55 dB	55 dB	57 dB	45 dB
FM4	63 dB	72 dB	70 dB	65 dB
FM5	69 dB	78 dB	77 dB	71 dB
FM Mean	**60 dB**	**66 dB**	**65 dB**	**58 dB**
FM St. Dev	**6.23**	**8.96**	**8.62**	**10.66**
M1	61 dB	65 dB	69 dB	62 dB
M2	66 dB	70 dB	64 dB	56 dB
M3	62 dB	65 dB	64 dB	55 dB
M4	67 dB	71 dB	70 dB	69 dB
M5	58 dB	69 dB	71 dB	65 dB
M Mean	**63 dB**	**68 dB**	**68 dB**	**61 dB**

M St. Dev.	**3.70**	**2.83**	**3.36**	**5.94**

Table 3E: Intensity Results

6.1 Intensity in Female and Male Pronunciation

The female participants produced 70 out of the 90 putative stressed syllables louder than the unstressed ones. This amounts to 77.77%. The male speakers also stressed 68 out of 90 putative stressed syllables (75.55%). The intensity produced by the female and male participants in our study is in keeping with what has been reported elsewhere in the literature. French and Steinberg (1947, p. 93) note that the intensity of male speakers is on average 3 dB louder than that of their female counterparts. Our data supports this finding. The mean intensity of the 180 syllables produced by the females is 59.69 dB versus 63.67 dB for male speakers.

7.0 Summary

In section in 3.0, it was noted that studies investigating the acoustic correlates of lexical stress have yielded different results. Our main findings, summarized in Table 4A, add to the ongoing controversy:

Participants	**F0**	**Duration**	**Intensity**
Females	50/90 = 58.88%	55/90 = 61.11%	70/90 = 77.77%
Males	73/90 = 81.11%	60/90 = 66.66%	68/90 = 75.55%

Table 4A: Overall Ranking

Our data shows two different rankings based on the participants' gender. Female participants encode lexical stress by ranking their correlates as follows: Intensity > Duration > F0. The ranking in male speech is F0 > Intensity > Duration. The strategy used by male speakers aligns with Fry's findings, whereas the one used by females speakers agrees with Kochanski et al's ranking.

In Table 4B, we provide a deeper analysys to highlight interspeaker variability in correlate ranking:

Speaker	**F0**	**Duration**	**Intensity**	**Ranking**
FM1	72.22%	77.78%	66.67%	Duration > F0 > Intensity
FM2	50%	72.22%	83.33%	Intensity > Duration > F0
FM3	72.22%	55.56%	83.33%	Intensity > F0 > Duration
FM4	55.56%	83.33%	88.89%	Intensity > Duration > F0
FM5	83.33%	61.11%	77.78%	F0 > Intensity > Duration
M1	83.33%	72.22%	77.78%	F0 > Intensity > Duration
M2	83.33%	66.67%	72.22%	F0 > Intensity > Duration
M3	88.89%	72.22%	72.22%	F0 > Intensity = Duration
M4	61.11%	61.11%	61.11%	F0 = Intensity = Duration
M5	50%	72.22%	83.33%	Intensity > Duration > F0

Table 4B: Ranking by Individuals

The majority of the participants, three out of five females, rely on intensity to encode lexical stress. Similarly, three out of the five male participants encode lexical stress by relying primarily on F0. The fact that individual speakers rank their correlates differently should not come as a surprise. Fry (1955, p. 765) alluded to it saying, "There was considerable variation in the behavior of the speakers with respect to the placing of the accent in different words."

If these gender-based differences are verified in large scale studies, they would have implications for designing smarter automatic speech recognition (ASR), text-to-speech (TTS), and hearing aid devices. To the best of our knowledge, this is the only study that has ranked the acoustic correlates of lexical stress by gender. Other studies should follow suit to validate or invalidate our findings. We are fully aware that our study has limitations: a small sample size, a narrowly focused demographic (college-aged students), and an ethnically and linguistically homogeneous pool of participants (all Caucasions from Central Minnesota). Future research should investigate how different demographics rank their acoustic correlates of lexical stress. Such an investigation would necessarily include older adults, namely those 65 and older since many of them will likely need hearing devices sooner rather than later (Hazan (2017, p. 39). Last but not least, this investigation should be expanded to Northern Minnesota, especially to the Iron Range, to determine the extent to which dialect variations affect the ranking of the acoustic correlates of lexical stress. We have the Iron Range region in mind because, by all impressionistic accounts, this area has a noticeably different dialect from the rest of Minnesota.

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