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Ettien Koffi
St. Cloud State University, enkoffi@stcloudstate.edu

Michel Lopez-Backstrom
michel.backstrom@gmail.com

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THE ACOUSTIC CORRELATES OF ALVEOLAR FRICATIVES IN THE IDIOLECT OF A NORTHERN MINNESOTA FEMALE

ETTIEN KOFFI AND MICHEL LOPEZ-BACKSTROM[1]

ABSTRACT

This study investigates the acoustic correlates of the sibilant alveolar fricatives [s] and [z] in the first author's idiolect. The corpus consists of 32 words containing 13 word-initial [s]s, six word-medial [s]s, and 13 word-final [z]s. The 32 words are extracted from two texts read in running speech. All in all, 160 tokens are measured acoustically (32 fricatives x 5 correlates). The correlates in question are Center of Gravity, intensity, F2, duration, and voicing attributes. The findings indicate that only Center of Gravity and duration are significant correlates for differentiating between the alveolar fricatives [s] and [z] produced by the second author. This study adds to the existing acoustic phonetic body of knowledge (Hennen and Koffi 2017, Wallin and Koffi 2017, Koffi and Lundy 2017) about the pronunciation of sibilant fricatives in Minnesota English. The findings show that voicing is not a robust cue for discriminating between [s]s and [z]s in word-final positions in the dialect of American English spoken in this region because of very strong coda devoicing tendencies.

1.0 An Overview of the Acoustic Characteristics of Fricatives

Fricatives, especially the sibilants [s] and [z], are very "noisy" because they are produced with a great amount of frication (Jongman 2000: 1261). The turbulence is created as a result of high velocity air molecules passing through a narrow channel (Koffi 2017: 177). The air molecules gushing out of the constricted area collide with the alveolar ridge at a very high speed. This explains why [s] and [z] are considerably noisier than other fricatives such as [ʃ, ʒ, f, v, θ, ð, h]. Even so, there are considerable interspeaker variations in how [s] and [z] are produced. Ladefoged and Maddieson (1996: 146) remark in this regard that "The amount of protuberance of the alveolar ridge, and the relation between the lower jaw and the upper teeth as two factors that lead to articulatory and perceptual differences in the production of fricatives." On page 137, they observe that adjustment as small as 1 mm in the air channel can affect the acoustic characteristics of fricatives. Additionally, Koffi and Bloch (2017: 46) and others reported that gender differences exist in the production of fricatives in Central Minnesota English (CMNE). This paper is part of an ongoing investigation on the acoustic phonetic cues that talkers and hearers in Minnesota use to encode differences between fricatives. In the current study, we are particularly interested in investigating which acoustic correlates the second author who is from Northern Minnesota relies on to differentiate between [s] and [z]. The correlates considered are the following:

1. Center of Gravity (COG)
2. Intensity
3. F2

[1] **Authorship responsibilities:** The second author enrolled in the acoustic phonetics course taught by the first author. She wrote an earlier version of this paper to fulfill the requirements of the course. The first author has interpreted the measurements made by the second author and rewritten the current version of the paper according the Speech Intelligibility framework. The second author has read the present version of the paper and agrees with its content. The first author assumes full responsibility of any erroneous interpretation of the data.

4. Duration
5. Voicing ratio

The nine fricatives of English are classified by place of articulation as follows: two labiodenals [f, v], two interdentals [θ, ð], two alveolars [s, z], two palatals [ʃ, ʒ], and one glottal [h]. In all these doublets, the first is voiceless, while the second is voiced.

2.0 The Corpus and the Methodology

The students enrolled in the acoustic phonetics course taught by the first author are required to record themselves reading the following text as naturally as possible. The text is a slightly adapted version from the one at Speech Accent Archive (http://accent.gmu.edu/). The words in red contain the sibilant segments investigated in this paper.

> *Please call Stella. Ask her to bring these things with her from the store: Six good spoons of fresh snow*[2] *peas, five thick slabs of blue cheese, and maybe a foot-long sandwich as a snack for her brother Bob. We also need a small plastic snake, a yellow book, a rubber duck, a paper I-pad, the dog video game, a big toy frog for the kids, but not the faked gun. She can scoop these things into three red bags and two old backpacks, and we will go meet her, Jake, and Jenny Wednesday at the very last train station at the edge of the zoo near York's Treasure Bank.*

In addition to the text above, the second author recorded herself on a Sony IC Recorder ICD-PX440 with a Logitech G230 Gaming Headset reading 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.

The recordings were analyzed in Praat, an online software package used for acoustic phonetic measurements and analyses. Figure 1 shows how the [s] and [z] segments derived from the 32 lexical items are annotated and measured acoustically:

[2] The word <snow> begins with a word-initial [s]. However, this [s] is not included in the investigation because the second author produced it as [ʃ]. This is a case of progressive assimilation. The [ʃ] in the coda of <fresh> causes the [s] at the beginning of <snow> to be produced as [ʃ]. Thus, she pronounced the phrase <fresh snow peas> as [fɹɛʃ ʃno pi:z].

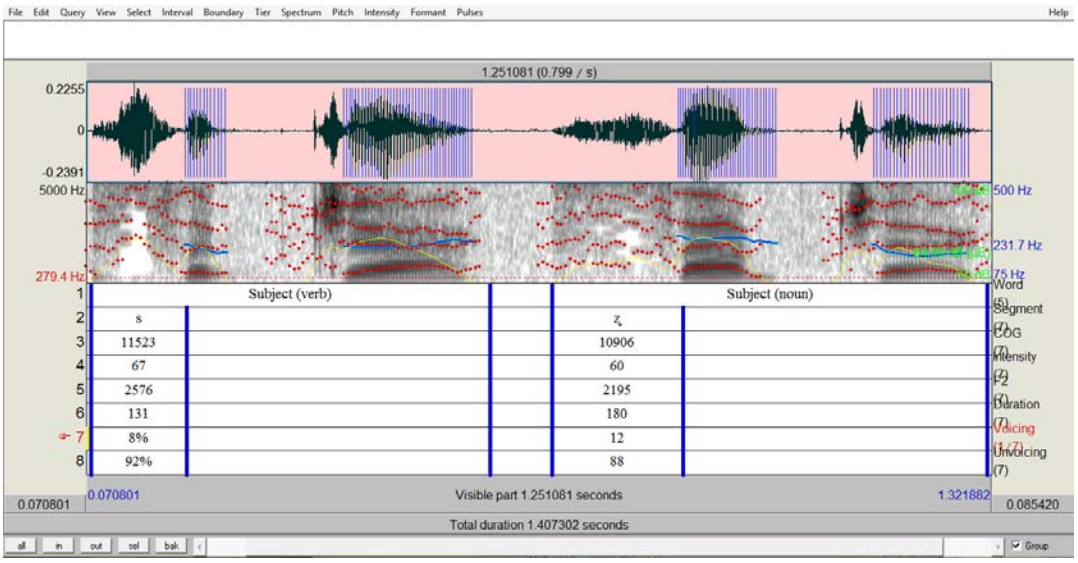

Figure 1: Annotations of the [s] in <subject>

The total number of sibilant fricatives are listed in Tables 2 and 3 according to their voicing characteristics and their distributions. Table 2 contains all the words in which the voiceless [s] occurs, while Table 3 contains words with the voiced [z]:

NO	Words	Transcription	NMNE Realizations	Environments
1.	**S**tella	[stɛ́lɑ]	[s̪tɛ́lɑ]	Word-initial
2.	**S**tore	[stoɹ]	[stoɹ]	Word-initial
3.	**S**ix	[siks]	[sɪks]	Word-initial
4.	**S**poons	[spunz]	[spʊns]	Word-initial
5.	**S**labs	[slæbz]	[slæb̪z̪]	Word-initial
6.	**S**andwich	[sa̰ndwɪtʃ]	[s̪á̰nd˺wəʒ]	Word-initial
7.	**S**nack	[snæk˺]	[s̪næk˺]	Word-initial
8.	**S**mall	[smɑl]	[smɑ]	Word-initial
9.	**S**nake	[snek]	[snek]	Word-initial
10.	**S**coop	[skup]	[skup]	Word-initial
11.	**S**tation	[stéʃə̰n]	[s̪téʃə̰n]	Word-initial
12.	**S**ubject (verb)	[sɪbdʒɛ́kt]	[sɪb̪˺dʒɛ́kt]	Word-initial
13.	**S**ubject (noun)	[sʌ́bdʒəkt]	[s̪ʌ́b̪˺dʒɪkt]	Word-initial
14.	Si**x**	[siks]	[sɪks]	Word-final
15.	Backpack**s**	[bækpʰæks]	[b̪æk˺pʰæks]	Word-final
16.	York’**s**	[joɹks]	[joɹks]	Word-final
17.	Produ**ce** (verb)	[pɹədús]	[pɹəd̪uz̪]	Word-final
18.	Produ**ce** (noun)	[pʰródus]	[pɹodu z̪]	Word-final
19.	Refu**se** (noun)	[rífus]	[rə́fu z̪]	Word-final

Table 2: Voiceless [s]

NO	Words	Transcription	NMNE Realizations	Environments
1.	**Z**oo	[zu]	[z̬u]	Word-initial
2.	Plea**se**	[pliz]	[plis]	Word-final
3.	The**se**1	[ðiz]	[niz̬]	Word-final
4.	Thing**s**1	[θiŋz]	[θiŋs]	Word-final
5.	Spoon**s**	[spunz]	[spʊns]	Word-final
6.	Pea**s**	[piz]	[pis]	Word-final
7.	Slab**s**	[slæbz]	[slæb̥z̬]	Word-final
8.	Chee**se**	[ʧiz]	[ʧiz]	Word-final
9.	Kid**s**	[kɪdz]	[kɪtz̬]	Word-final
10.	The**se**2	[ðiz]	[d̪is]	Word-final
11.	Thing**s**2	[θiŋz]	[θiŋs]	Word-final
12.	Bag**s**	[bægz]	[b̥ægz̬]	Word-final
13.	Refu**se** (verb)	[rəfuz]	[rəfús]	Word-final

Table 3: Voiced [z]

Subsequent analyses focus on each one of the five acoustic correlates listed in 1.0. We begin with Center of Gravity (COG) and conclude with voicing ratios.

2.1 Center of Gravity

Center of gravity (COG) is generally referred to as the acoustic correlate which measures the acoustic energy of a fricative by pinpointing its place of articulation (Wallin and Koffi: 2017, 105). It has been likened by Koffi and Bloch (2017: 39) to a hurricane. Using a meteorological metaphor, COG has been compared to the "eye of the storm." In other words, COG measures the highest frequency points in the pronunciation of fricatives. A study by Wallin and Koffi (2017: 104) found that "the COG of [s] and [z] is concentrated around 6000 Hz and extends above that." Jongman (2000: 1256) reports that the COG of [s] and [z] produced by the female participants in his study is around 7500 Hz.

In this study, we are interested on measuring the COG of [s] and [z] separately to see how the second author produces them. If the acoustic distance between them is ≥ 630 Hz, it means that she produces them differently. If the frequency difference is below the 630 Hz Just Noticeable Difference (JND), it means that she pronounces them similarly. For additional information about the use of this JND to assess intelligibility, readers may want to refer to Koffi and Bloch (2017: 41) for a fuller discussion. Koffi and Ribeiro (2016: 92-93) used the same JND threshold to determine whether or not a Brazilian Portuguese English (BPE) speaker differentiated between her [s]s (8835 Hz) and her [z]s (7567 Hz). Since the COG distance between her sibilant fricatives was 1268 Hz, it was concluded based on the JND threshold that she produced them distinctly. They went one step further and noted that she dentalized her [s]s, but produced her [z]s in the alveolar area. This finding is consistent with Ladefoged and Maddieson (1996: 146-147) who have reported that dentalized [s] is typical in many languages.

The COG measurements in Table 4 provide us with a lot of detailed information about the second author's pronunciation of [s] and [z]. However, for the sake of brevity, we will only focus on mean measurements in assessing the similarities and differences in her pronunciation of these sibilant fricatives.

NO	Word	Segments	COG	Word	Segments	COG
1.	**S**tella	[s]	11133	Plea**se**	[z]	9616
2.	**S**tore	[s]	7863	The**se**1	[z]	10758
3.	**S**ix	[s]	9193	Thing**s**1	[z]	5787
4.	**S**poons	[s]	6239	Spoon**s**	[z]	6303
5.	**S**labs	[s]	8573	Pea**s**	[z]	7463
6.	**S**andwich	[s]	8693	Slab**s**	[z]	4807
7.	**S**nack	[s]	9368	Chee**se**	[z]	6819
9.	**S**mall	[s]	9407	Kid**s**	[z]	9180
9.	**S**nake	[s]	9648	The**se** x 2	[z]	7616
10.	**S**coop	[s]	7355	Thing**s** x 2	[z]	9117
11.	**S**tation	[s]	8132	Bag**s**	[z]	7456
12.	**S**ubject (V)	[s]	11523	Refu**se** (V)	[z]	6853
13.	**S**ubject (N)	[s]	10906	**Z**oo	[z]	5856
14.	Si**x**	[s]	8302			
15.	Backpack**s**	[s]	6773			
16.	York'**s**	[s]	6830			
17.	Produ**ce** (V)	[s]	4901			
18.	Produ**ce** (N)	[s]	7499			
19.	Refu**se** (N)	[s]	7772			
	Mean		**8426 Hz**			**7510 Hz**
	St. Deviation		**1707 Hz**			**1726 Hz**

Table 4: COG of [s] and [z]

The COG distance between [s] (8426 Hz) and [z] (7510 Hz) is 916 Hz. Since this exceeds the Just Noticeable Difference (JND) threshold of 630 Hz, it can be concluded that the second author's [s] is more fronted than [z]. Consequently, COG is a robust cue for discriminating between her [s]s and [z]s. We note in passing that there are striking similarities between the second author's pronunciation and that of the BPE speaker alluded to in the previous paragraph.

2.2 Intensity

Intensity correlates impressionistically with loudness. Ladefoged and Maddieson (1996: 139) have reported that intensity is a robust cue for discriminating among voiced and voiceless fricatives. There is a wide consensus among physicists, acousticians, audio engineers, audiologists, and other experts that 3 dB is the minimum threshold to perceive that two signals differ in loudness. See Koffi (2017:103) for a review of the relevant literature. This is the JND threshold that is used to determine whether or not the second author produces her [s]s and [z]s similarly.

NO	Word	Segment	Intensity	Word	Segment	Intensity
1.	**S**tella	[s]	60	Plea**se**	[z]	60
2.	**S**tore	[s]	62	The**se**1	[z]	57
3.	**S**ix	[s]	58	Thing**s**1	[z]	58
4.	**S**poons	[s]	63	Spoon**s**	[z]	58
5.	**S**labs	[s]	58	Pea**s**	[z]	58
6.	**S**andwich	[s]	57	Slab**s**	[z]	54
7.	**S**nack	[s]	65	Chee**se**	[z]	57

9.	**S**mall	[s]	63	Kid**s**	[z]	55
9.	**S**nake	[s]	59	The**se** x 2	[z]	59
10.	**S**coop	[s]	68	Thing**s** x 2	[z]	62
11.	**S**tation	[s]	63	Bag**s**	[z]	58
12.	**S**ubject (verb)	[s]	67	Refu**se** (verb)	[z]	59
13.	**S**ubject (noun)	[s]	60	**Z**oo	[z]	62
14.	Si**x**	[s]	57			
15.	Backpack**s**	[s]	55			
16.	York'**s**	[s]	60			
17.	Produ**ce** (verb)	[s]	63			
18.	Produ**ce** (noun)	[s]	60			
19.	Refu**se** (noun)	[s]	57			
Mean			**60.78 dB**			**58.23 dB**
St. Deviation			**3.55 dB**			**2.31 dB**

Table 5: Intensity of [s] and [z]

The overall intensity of the second author's [s]s is 60.78 dB, while her [z]s is 58.23 dB. The intensity difference between them sits at 2.55 dB. Since this is below the JND of 3 dB, we conclude that first author does not discriminate between them in intensity. We will see in 2.5 that the lack of discrimination in intensity may also be attributed to coda devoicing.

2.3 Duration

Hennen and Koffi (2017) found that one speaker of CMNE discriminates between fricatives in duration. Jongman (2000:1262) also found duration to be a robust correlate for distinguishing between voiced and voiceless fricatives. However, Gordon's (2000:32) study of fricatives in seven Native American languages led him to conclude that duration was "the least informative parameter for discriminating the fricatives." In determining whether or not duration is a robust cue in the speech of the second author, we will rely on the JND of ≥ 10 ms that is unanimously accepted as a valid reference level for determining if one signal is longer than another. The JND ≥10 ms is most appropriate for segments lasting less than 200 ms. For those lasting 200 ms or longer, the optimal JND is ≥17 ms.

NO	Word	Segment	Duration	Word	Segment	Duration
1.	**S**tella	[s]	113	Plea**se**	[z]	88
2.	**S**tore	[s]	95	The**se**1	[z]	93
3.	**S**ix	[s]	90	Thing**s**1	[z]	54
4.	**S**poons	[s]	101	Spoon**s**	[z]	46
5.	**S**labs	[s]	135	Pea**s**	[z]	155
6.	**S**andwich	[s]	152	Slab**s**	[z]	79
7.	**S**nack	[s]	152	Chee**se**	[z]	194
9.	**S**mall	[s]	159	Kid**s**	[z]	108
9.	**S**nake	[s]	90	The**se**2	[z]	102
10.	**S**coop	[s]	105	Thing**s**2	[z]	71
11.	**S**tation	[s]	89	Bag**s**	[z]	110
12.	**S**ubject (verb)	[s]	131	Refu**se** (verb)	[z]	104
13.	**S**ubject (noun)	[s]	180	**Z**oo	[z]	193
14.	Si**x**	[s]	96			
15.	Backpack**s**	[s]	175			

16.	York'**s**	[s]	83			
17.	Produ**ce** (verb)	[s]	107			
18.	Produ**ce** (noun)	[s]	219			
19.	Refu**se** (noun)	[s]	319			
Mean			**136 ms**			**107 ms**
St. Deviation			**58 ms**			**46 ms**

Table 6: Duration of [s] and [z]

The second author produces her [s]s (136 ms) longer than her [z]s (107 ms) by 29 ms. This shows convincingly that she relies on duration to encode a difference between her voiced and voiceless sibilants. Her pronunciation is in line with Jongman (2000:1262)'s findings that in American English, voiceless fricatives have a longer duration than their voiced counterparts.

2.4 F2

The second formant (F2) correlates with the horizontal tongue movements. Segments produced towards the front of the mouth are given the phonetic feature [+anterior] in the description of consonants, while those produced elsewhere are considered [-anterior]. The alveolar ridge is the divide between [+anterior] and [-anterior] segments. When vowels are involved, there is a three-way distinction: [+front], [+central], and [+back]. When these phonetic features are translated into acoustic phonetic measurements, they lead to the thresholds: F2 measurements of $\geq$ 2000 Hz corresponds to [+anterior]/[+front], those between 1800 and 1400 Hz are considered [+central], and those whose F2 values are $\leq$ 1400 Hz are [-anterior]/[+back]. These thresholds are based on the Critical Band Theory (CBT), as explained in Koffi (2017: 103). Let's examine the data in Table 7 to see how the second author produces her [s]s and [z]s:

NO	Word	Segment	F2	Word	Segment	F2
1.	**S**tella	[s]	2122	Plea**se**	[z]	2251
2.	**S**tore	[s]	2427	The**se**1	[z]	2255
3.	**S**ix	[s]	2077	Thing**s**1	[z]	2363
4.	**S**poons	[s]	2495	Spoon**s**	[z]	2010
5.	**S**labs	[s]	2339	Pea**s**	[z]	2253
6.	**S**andwich	[s]	2262	Slab**s**	[z]	2562
7.	**S**nack	[s]	2505	Chee**se**	[z]	2160
9.	**S**mall	[s]	2247	Kid**s**	[z]	2197
9.	**S**nake	[s]	2373	The**se** x 2	[z]	2186
10.	**S**coop	[s]	2997	Thing**s** x 2	[z]	2208
11.	**S**tation	[s]	2222	Bag**s**	[z]	2216
12.	**S**ubject (verb)	[s]	2576	Refu**se** (verb)	[z]	2292
13.	**S**ubject (noun)	[s]	2195	**Z**oo	[z]	2589
14.	Si**x**	[s]	2226			
15.	Backpack**s**	[s]	2032			
16.	York'**s**	[s]	2263			
17.	Produ**ce** (verb)	[s]	3170			
18.	Produ**ce** (noun)	[s]	2539			
19.	Refu**se** (noun)	[s]	2203			
Mean			**2382 Hz**			**2272 Hz**
St. deviation			**292 Hz**			**157 Hz**

Table 7: F2 of [s] and [z]

On the F2 frequency bandwidth, a minimum distance (i.e. JND) of 200 Hz is required to determine that two signals are perceptually different. In other words, if the acoustic distance between second author's [s]s and [z]s is less than 200 Hz, this means that she produces them in the same area of the mouth. The mean measurements show that her [s]s and [z]s are respectively 2382 Hz and 2272 Hz. The acoustic distance of 110 Hz is below the JND threshold of 200 Hz. In other words, she produces both her [s]s and [z]s as [+anterior]. The F2 measurements align with the COG in confirming the second author dentalizes her [s]s.

2.5 The Acoustic Correlates of Voicing

In world languages as well as in English, fricatives fall into two broad categories depending on their phonation type. Those produced with vocal fold vibrations are referred to as [+voiced], those without are labeled [-voice]. Accordingly, [s] is voiceless, while [z] is voiced. However, studies have shown that voicing is gradient, not binary. In other words, there are several shades of voicing. Smith (1997) has made some very fine distinctions between various degrees of voicing in English fricatives. Koffi and Laundy (2017) found incremental degrees of voicing in Central Minnesota English among both males and females.

Gradoville (2011: 68) found that the participants in his study categorized a segment as voiced if 40% of its duration is voiced. This led him to posit the 40/60 threshold. Koffi has used the Voice Report feature in Praat in many measurements and has confirmed that the 40/60 threshold reliably accounts for a binary perception of voicing. Koffi and Lundy Koffi (2017: 119) have combined insights from Smith (1997) and from Gradoville and come up with the following gradations in voicing:

1. If 10% or less of the total duration of a segment is voiced, it is voiceless.
2. If 40% or more of the total duration of a segment is voiced, it is voiced.
3. If 60% to 90% of the total duration of a segment is unvoiced, it is devoiced.

These thresholds are applied to the measurements in Table 8 to determine the degrees of voicing in the second author's pronunciations of [s] and [z]:

NO	Word	Segment	% Voicing	% Unvoicing	Word	Segment	% Voicing	% Unvoicing
1.	**S**tella	[s]	10	90	**Z**oo	[z]	0	100
2.	**S**tore	[s]	0	100	Plea**se**	[z]	12	88
3.	**S**ix	[s]	0	100	The**se**1	[z]	0	100
4.	**S**poons	[s]	0	100	Thing**s**1	[z]	0	100
5.	**S**labs	[s]	0	100	Spoon**s**	[z]	0	100
6.	**S**andwich	[s]	7	93	Pea**s**	[z]	13	87
7.	**S**nack	[s]	27	73	Slab**s**	[z]	43	57
9.	**S**mall	[s]	0	100	Chee**se**	[z]	37	63
9.	**S**nake	[s]	0	100	Kid**s**	[z]	0	100
10.	**S**coop	[s]	0	100	The**se**2	[z]	0	100
11.	**S**tation	[s]	23	77	Thing**s**2	[z]	9	91
12.	**S**ubject (verb)	[s]	8	92	Bag**s**	[z]	10	90
13.	**S**ubject (noun)	[s]	12	88	Refu**se** (verb)	[z]	16	84

14.	Si**x**	[s]	0	100				
15.	Backpack**s**	[s]	0	100				
16.	York'**s**	[s]	0	100				
17.	Produ**ce** (verb)	[s]	30	70				
18.	Produ**ce** (noun)	[s]	14	86				
19.	Refu**se** (noun)	[s]	21	79				
Mean			**8%**	**92%**			**10%**	**89%**
St. Deviation			**10%**	**10%**			**14**	**14**

Table 8: Voicing Ratios of [s] and [z]

Three patterns emerge with regard to the pronunciation of sibilants. Overall, the percentage of voicing in [s] is 8%, which according to the thresholds in the previous sections corresponds to a voiceless segment. The overall percentage of voicing of [z] is 10%. This also means that [z] is voiceless. However, when we look closer at the data, we see some important differences. In word-medial positions, the amount of voicing in [s] is 6%, whereas that of [z] is 16%. In other words, in this position, the second author devoices her [z]s. At the end of words, both [s] and [z] are produced similarly, that is, only 10% of voicing. Clearly, the second author does not make any voicing distinction between word-initial and word-final alveolar sibilants. The only environment where she discriminates between her [s]s and [z]s is in word-medial environments.

3.0 Summary

Of the five acoustic correlates measured in this study, the data shows that the second author relies on two to encode a distinction between [s] and [z]. The two are COG and duration. COG shows that she dentalizes her [s], but not her [z]s. Duration is by all accounts the most robust cue that she depends on. Her [s]s exceeds her [z]s according the JND threshold in duration by 19 ms! F2, intensity, and voicing correlates are not robust. The F2 measurements show that her [s]s are more fronted (dentalized) than her [z]s. However, the difference is not acoustically salient because it is below the JND threshold of 200 Hz. Intensity is also not a robust cue in her pronunciation because the distance between her [s]s and [z]s is less than the minimum 3 dB required for intelligibility. This is not surprising since she devoices her word-final [z]s and produces them in the same way as she pronounces her [s]s. Acoustically-speaking, duration and COG are the primary correlates that she and her interlocutors are likely rely on to encode or decode the differences between her [s]s and [z]s.

ABOUT THE AUTHORS

Ettien Koffi, Ph.D., is a professor of Linguistics at St. Cloud State University, Minnesota, USA, specializing in acoustic phonetics (Speech Intelligibility). His research interests center around sociophonetic variations in Central Minnesota English, acoustic phonetic accounts of intelligibility in L2 English, and acoustic phonetic and general description of Anyi, a West African Language spoken in Cote d'Ivoire. He is the author of four books and numerous papers covering topics as varied as syntax, translation, language planning and policy, orthography, and indigenous literacy training manuals. He can be reached at enkoffi@stcloudstate.edu.

Michel Lopez-Backstrom, MA-candidate, is a Spanish and ESL teacher in the Howard Lake-Waverly-Winsted school district in Minnesota. She is currently completing her MA in Teaching English as a Second Language at St. Cloud State University, Minnesota, USA. She studies under Dr. Ettien Koffi and is writing her MA thesis on the acoustic phonetic vowel space of Northern Minnesota English. She can be reached at michel.backstrom@gmail.com.

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