Maximum Duration of Sustained /s/ and /z/ and the s/z Ratio With Controlled Intensity

*Marylou Pausewang Gelfer and †John F. Pazera

*Milwaukee, Wisconsin, and †San Diego, California

Summary: The purpose of this study was to compare maximum prolongations of controlled-intensity /s/ vs. /z/ in young healthy male and female adults and to compare the s/z ratio in young men and women. Twenty young adult men and 20 young adult women were included in this study. Participants produced 10 trials of /s/ and 10 of /z/ with a controlled intensity of 60-dB sound-pressure level (SPL). Maximum prolongations and s/z ratio were determined by three different methods: based on the longest out of 10 trials, the longest of 3 trials, and an average of the first 3 trials. Results revealed that based on averaged group data, /s/ and /z/ seemed to be prolonged for similar durations. Men consistently prolonged both phonemes significantly longer than women. There were no significant differences in s/z ratio between men and women. However, when individual data were reviewed, it seemed that some subjects consistently prolonged /s/ for a longer duration than /z/, some subjects prolonged /z/ longer than /s/, and some subjects actually produced approximately equal durations of the two phonemes. It was further noted that /s/ durations were more favorably impacted by practice than /z/ durations.

Key Words: s/z ratio—Maximum prolongations—Mean phonation duration—Young adults.

INTRODUCTION

The s/z ratio is a measure of differential duration that has been suggested for diagnostic use in voice evaluations. According to Boone, who first developed this technique, persons with normal vocal folds could be expected to prolong the voiceless /s/ and the voiced /z/ phonemes for about the same length of time, resulting in an s/z ratio of approximating 1. Eckel and Boone also hypothesized that patients with laryngeal pathologies, such as lesions on the vocal fold margins, would have difficulty prolonging the voiced sound /z/ for the same duration as voiceless /s/, because of a “decrement in (glottal) efficiency,” which is the result of “a decrease in glottal resistance, increasing air flow with a shortened phonation time” (p. 147).

Several studies have since been performed in an effort to establish maximum durations for /s/ and /z/ prolongation and s/z ratio normative data. These studies have been inconsistent in both procedures and results. Procedurally, studies have differed in the aspects of type of instructions, number of trials,
type and number of subjects, variables controlled
(eg, loudness, pitch, motivation, training, respiratory
effort), and age of the subjects. Differences in
results (which could exist because of varying
procedures) include disagreements over even such
basic issues as the original premise of the s/z ratio:
that both phonemes should be produced for
approximately the same duration in vocally healthy
subjects, resulting in an s/z ratio of 1.

One justification for the expectation of similar
durations of /s/ and /z/ prolongations in vocally
healthy subjects was provided by Mueller et al. These
authors hypothesized that the overall airway
configuration and resistance for /s/ and /z/ could be
expected to be equivalent; thus, both sounds would
be likely to require similar driving pressures and
airflow rates, resulting in similar maximum dura-
tions. However, if Eckel and Boone’s ideas of
glottal resistance and efficiency are extended to
healthy subjects, there are also reasons to hypo-
etize that /z/ may be prolonged for a greater
duration than /s/ in vocally healthy subjects. For
example, /z/ production may involve lower glottal
airflow rates and increased glottal efficiency
because of the increased glottal resistance associ-
ated with vocal fold vibration. A subject’s /s/
production, on the other hand, may yield sub-
stantially greater airflow and reduced efficiency
because of an open glottal configuration. Pre-
sumably, higher airflow would reduce maximum
phonation time for /s/ compared with /z/. In fact,
this justification for longer /z/ prolongations was
suggested by Tait et al., who stated that if /z/
typically exceeds /s/ in duration, it “may reflect
conservation in air flow because of laryngeal valing” (p. 245).

Studies on persons with normal larynges indicate
considerable variability in the s/z ratio. Tait et al., in a study of 5-, 7-, and 9-year-old children, found
that for almost all of their subjects, /z/ was
produced with a slightly longer duration than /s/.
They found mean s/z ratios of 0.88 for 5-year-olds,
0.74 for 7-year-olds, and 0.92 for 9-year-olds. By
contrast, Fendler and Shearer, who studied first
and second-grade children, found an average s/z
ratio of 1.36 for the first-graders and 1.16 for the
second-graders. Ratios in excess of one suggest that
most children could sustain /s/ longer than /z/. The
mean value of 1.36 for first-graders was especially
interesting, given Eckel and Boone’s finding that
95% of their subjects with vocal nodules had s/z
ratios in a similar range (1.4).

One possible explanation for the differences
observed between the results of Tait et al. and
Fendler and Shearer may be that Tait et al.
controlled intensity, at least on one trial, through
the use of a “decibeloscope.” This instrument had
a light panel that lit up when the child’s intensity
reached 65–70 dB. Children were instructed to keep
the lights on the decibeloscope illuminated during
their prolongations.

Results for s/z ratio in adults have also shown
some inconsistency in terms of which phoneme, /s/
or /z/, is typically produced for a longer duration.
Eckel and Boone reported that in adults with
normal larynges, /s/ and /z/ were held for
approximately the same durations, although /z/
tended to be held very slightly longer (17.73 s for
/s/ vs. 18.60 s for /z/ for an s/z ratio of 0.99).
Soman also found a slight increase in the duration
of /z/ compared with /s/ when she cued her subjects
with verbal instructions only (23.47 s for /s/ vs.
26.66 s for /z/ for an s/z ratio of 0.91). However,
when she provided models and more detailed
instructions, subjects tended to produce /s/ for
a longer period, which resulted in s/z ratios of 1.19
to 1.37. Neither of these researchers controlled for
intensity of /s/ and /z/ productions, and neither
measured airflow.

Minor differences in the s/z ratio, and whether /s/
or /z/ was sustained for a greater duration, would
not warrant investigation if the s/z ratios of persons
with healthy larynges were in fact markedly
different from those of persons with vocal dis-
orders. However, a review of the literature on s/z
ratio confirms that there is considerable overlap in
the s/z ratios of those with and without laryngeal
pathology. For example, in children with normal
larynges, Tait et al. found s/z ratios of 0.67–0.92, as
described above. Rastatter and Hyman studied
children with laryngeal pathologies and found s/z
ratios of 0.81–0.93. Neither their male nor their
female subjects showed the expected reduction in
/z/ prolongation as a result of nodules. In a similar
vein, Hufnagel and Hufnagel found s/z ratios of
0.84 for male children with vocal nodules and of

1.03 in females with vocal nodules. Although the 1.03 figure may be suggestive that children with s/z ratios over one may be at risk for nodules, it should also be acknowledged that Larson et al.\textsuperscript{13} found s/z ratios of 0.90–1.12 in children with health larynges, whereas Fendler and Shearer\textsuperscript{9} found s/z ratios of 1.13–1.42 in a similar healthy group.

The results for adults with vocal nodules are also inconclusive. Eckel and Boone's\textsuperscript{2} nodules group had an s/z ratio of 1.65, but a value that large has not been replicated. Treole and Trudeau\textsuperscript{14} found an s/z ratio of 1.44 in a pretherapy group of adult female subjects with vocal nodules. Sorensen and Parker\textsuperscript{15} found an s/z ratio of 1.24 in their nodules group. As described, Trudeau and Forrest's\textsuperscript{16} subjects with laryngeal lesions (nodules, polyps, and leukoplakia) produced an average s/z ratio of 1.09. The latter values fall squarely within the range of Soman's\textsuperscript{10} normal participants, whose group means ranged from 0.91 to 1.37.

Studies of persons with other types of vocal disorders have also failed to show the discriminatory power of s/z ratio. Gamboa et al.\textsuperscript{17} investigated the s/z ratio, among other vocal variables, in participants with Parkinson's disease vs. gender-matched controls. Results showed that the Parkinson's group had an s/z ratio of 0.76, compared with a ratio of 0.74 for the normal controls. Even when duration and severity were taken into account, persons with Parkinson's disease of longer duration (s/z = 0.74) or with more severe symptoms (s/z = 0.76) showed no differences in s/z ratio compared with those with a shorter duration (s/z = 0.78) and less severe symptoms (s/z = 0.76). Similarly, a study of persons with essential tremor compared with age- and gender-matched controls revealed no significant differences in s/z ratio, with values of 0.83 and 0.74, respectively.\textsuperscript{18}

In comparison with the above studies, s/z ratios of participants with unilateral vocal fold paralyses have shown marked abnormalities as well as marked improvement after surgical treatment. Schneider et al.\textsuperscript{19} studied the phonatory and respiratory abilities of 12 women and 16 men with unilateral vocal fold paralysis before and after vocal fold medialization thyroplasty. Phonatory evaluation included perceptual judgments, voice dysfunction analyses, voice range profiles, videostroboscopy, and s/z ratio. Results showed a significant decrease in s/z ratio from the preoperative (s/z = 3.4) to the postoperative evaluation (s/z = 1.7). Adams et al.\textsuperscript{20} who also studied voice pre- and postthyroplastic surgery, found a reduction in s/z ratio from 2.23 to 1.11. In a similar study by La Blance and Maves,\textsuperscript{21} 8 participants went from an average s/z ratio of 1.86 1 week before surgery to 1.19 after.

The data from studies of unilateral vocal fold paralyses support the hypothesis that difficulties with laryngeal valving reduce prolongation of voiced /z/ without affecting unvoiced /s/, resulting in an increased s/z ratio. However, the data from studies of vocal nodules and other space-occupying laryngeal lesions or neurological disorders do not support this hypothesis. Furthermore, it is unclear from studies of persons with normal larynges whether the underlying assumption of equivalent durations for /s/ and /z/ prolongation (and thus a s/z ratio of 1) is valid. Finally the issue of intensity of phoneme production cannot be ignored. As suggested by Mueller et al.,\textsuperscript{6} one hypothesis for why /s/ and /z/ prolongation should be equal is that overall airway configuration and resistance for /s/ and /z/ are similar. However, if one phoneme is produced more loudly than the other, then the resistances cannot be assumed to be equal.

If the s/z ratio is to have any clinical usefulness as an indicator of glottal efficiency, it is important to understand its nature and factors affecting its variability. Intensity should be taken into account in any future s/z ratio research, because increased intensity may be reflective of greater respiratory and/or vocal effort, which may affect laryngeal/airway resistance, and ultimately maximum phonation time.

The purpose of this study was to obtain data on controlled-intensity maximum prolongation times of /s/ and /z/ in healthy young adults and to determine s/z ratio during controlled-intensity productions. Specific research questions were as follows:

1. Do maximally- prolonged /s/ and /z/, produced with controlled intensity, have similar durations? Are there significant differences between men and women, or significant interactions between gender and phoneme?
2. Are there significant differences between men and women for s/z ratio?

It is hoped that studies such as this one will contribute to a better understanding of the s/z ratio and its potential applications.

**METHOD**

**Participants**

The participants for this study included 20 men and 20 women with normal vocal function. All were between the ages of 19 and 30 years. Mean age for men was 25:0 (years/months), with a range of 20:5 to 30:3. Mean age for women was 23:6, with a range of 19:10 to 29:6.

Participants were recruited from undergraduate communication sciences and disorders, psychology, and statistics classes at a large urban university. Criteria for inclusion in this study were as follows: (1) articulation within normal limits, as determined by administration of the Fisher–Logemann Test of Articulation Competence, Sentence version; (2) native speaker of English, as determined by questionnaire response; 3) no knowledge of or experience with the s/z ratio, as determined by subject report; and 4) no symptoms of a cold, upper respiratory infection, or allergy on the day of participation, as determined by questionnaire response and interview. In addition, the voice quality of each subject had to be “within normal limits” according to both the judgment of a certified speech-language pathologist and the results of a Multi-Dimensional Voice Program (MDVP; Kay Elemetrics Corp., Pinebrook, NJ) analysis. Persons were excluded from the study if they reported (via questionnaire and interview) any of the following: laryngitis or loss of voice within the 2 days before testing, history of vocal nodules or polyps, history of laryngeal surgery, or history of asthma.

**Materials**

Participants were screened for normal voice production using MDVP software run on the Computerized Speech Lab hardware system (CSL; Kay Elemetrics Corp.) The MDVP digitally records a 2-s vowel vocalization, analyzes it, and then provides a graphic display output that compares the performance of the subject with normative data for various measures of vocal perturbation and noise. Nineteen parameters can be calculated and displayed; however, for the purposes of this study, only nine were retained: absolute jitter in milliseconds, jitter percent, relative average perturbation, pitch period perturbation quotient, fundamental frequency variation, shimmer, shimmer percent, amplitude perturbation quotient, and peak amplitude variation. These parameters were selected because they are the most extensively researched and, in the opinion of the investigators, have the most valid norms.

Each prolongation of /s/ and /z/ was audiotaped with a Tandberg (InoStor Corp., Poway, CA) Educational TCR 522 MK2 audiotape recorder and a Tandberg TM6 unidirectional microphone. All maximum prolongation attempts were measured live with a digital stopwatch. A stopwatch has historically been used to calculate durations of /s/ and /z/ production for the s/z ratio and is specifically recommended by Colton and Casper for use by clinicians. A subset of attempts was later measured from audiotape, also with a digital stopwatch, for the calculation of reliability. Participant productions were maintained within a specific decibel range with the aid of a Realistic Sound Level Meter (Cat. No. 33-2050; Tandy Corporation, Regents Park, Australia).

**Procedures**

Participants were individually escorted to a quiet room where they filled out an initial questionnaire to determine eligibility for the study and human subjects consent forms. An interview was then conducted by the first author to follow up on any potentially exclusionary responses. If participants seemed eligible for the study, they were next asked to complete the MDVP voice screening. Each participant was instructed to produce a prolonged /a/ phoneme at a comfortable pitch and loudness while sitting in a chair directly in front of the CSL system microphone (12-in mouth-to-microphone distance). The first investigator provided an abbreviated model. Two seconds of each subject’s production of the /a/ phoneme were analyzed by the MDVP software to determine whether any of the nine selected vocal parameters were outside of
the norms programmed into the software. Participants producing vocalizations with voice breaks were required to try again and instructed to produce \(/z/\) with a “smooth, steady voice.” If participants passed the MDVP voice screening, they were then perceptually screened for voice quality and articulatory proficiency by the second investigator during the reading of the sentences comprising the Fisher–Logemann Test of Articulation Competence (Sentence Version). All eligible participants then went on to the experimental procedure.

The experimental procedure for this study required eligible subjects to produce 10 trials of both the \(/s/\) and the \(/z/\) phonemes for maximum duration. After a full clinician model by the second investigator, each participant was instructed to take a deep breath and produce \(/s/\) or \(/z/\) for as long as possible at a comfortable pitch level (for \(/z/\)) and at a loudness level of 58–62 dB (Weighting Network C, which approximates decibel sound pressure level (SPL), according to the instruction manual for the device). A target intensity level of 60 dB (SPL) with variation of ±2 dB was selected by the investigators after pilot trials to determine a comfortable intensity level at which both phonemes could be produced.

Participants stood in front of a sound level meter microphone and were asked to place their head against a positioning device to ensure a 12-in mouth-to-microphone distance. In this position, the sound level meter scale was clearly visible, so that visual feedback regarding intensity level was consistently available. Participants were given as many short-duration practice trials as needed to maintain \(/s/\) and \(/z/\) at the desired level (60 dB, ±2 dB) before beginning the experimental task of maximum sound prolongations. A tape recorder was positioned directly to the right of the subject, with its microphone next to the sound level meter microphone.

For the experimental task, participants were asked to produce 10 trials for each phoneme, with a 1-minute rest in between productions. We used 10 trials as a compromise figure. On one extreme, Lewis et al. found substantial increases in maximum phonation time through at least 20 trials for children; and Stone found improvement in performance through 15 trials for adults. On the other extreme, Neiman and Edeson found that with appropriate instruction and modeling, adults required 4–6 trials to produce their longest phonation. Both Stone and Finnegan found that the average trial on which subjects produced their longest phonation was the ninth. Thus, 10 trials were selected, with the goal of eliciting absolute maximum prolongation of \(/s/\) and \(/z/\) without undue fatigue.

During the rest period between trials, each subject was instructed by the investigator to “try to make the next one even longer.” Half of the participants were required to produce \(/s/\) first and then \(/z/\), whereas the other half produced \(/z/\) first and then \(/s/\). First and second phoneme productions were alternated for a total of 20 trials (10 of each phoneme). Production times were measured with a digital stopwatch by the second investigator. All productions were tape-recorded for later reanalysis.

**RESULTS**

Reliability data

Of the 800 prolongations of \(/s/\) and \(/z/\) produced by the subjects (10 \(/s/\) repetitions + 10 \(/z/\) repetitions = 20; 20 repetitions x 40 subjects = 800), 20% or 160 were remeasured from audiotape by the first investigator, so that inter-rater reliability could be assessed. Eighty of the remeasured samples were of \(/s/\) productions, and 80 were of \(/z/\) productions. Of the total 160 samples remeasured, 118 or 74% were within ±0–0.2 s of the first judgment; 24 or 15% were within ±0.3–0.5 s of the first judgment, and 18 or 11% were within ±0.6–2.2 s of the first judgment.

For the 80 remeasured samples of \(/s/\) productions, the average difference from the original judgment of duration was 0.24 s. For the 80 remeasured samples of \(/z/\), the average difference from the original judgment of duration was 0.23 s. Standard error, a measure of the expected variation in score upon repeated administrations of a test, was determined for \(/s/\) and \(/z/\) samples, respectively, by taking the standard deviation of the appropriate data set and dividing it by the square root of the total number of subjects. The standard error for the \(/s/\) data set was 1.65 s; for the \(/z/\) data set, it was 1.36 s. Thus, the actual variation between the first
and second duration judgments for both /s/ and /z/ was considerably less than the standard error, which indicates good reliability of the duration data.

If durational differences between the first and second judgments were found, the first investigator remeasured the sample from the tape to resolve discrepancies. If the third measurement did not correspond to either of the previous judgments, all values were averaged.

**Duration and s/z ratio data: maximum of 10 trials**

The maximum /s/ and /z/ durations taken from 10 trials can be seen in Table 1. Values on this table represent the absolute longest durations of /s/ and /z/ produced by each subject over the total of 10 trials. The results of the maximum duration task revealed similar durations for /s/ and /z/ regardless of gender, although men produced considerably longer durations of both phonemes than women. Furthermore, large ranges for each gender and phoneme combination were observed, which indicates a large degree of intersubject variability. The phoneme /s/ seemed to have more intersubject variability than /z/.

An analysis of variance (ANOVA) on duration with a repeated-measures factor for phoneme can be seen in Table 2. Only the main effect for gender was significant. The main effect for phoneme and the gender x phoneme interaction were not. As expected from the raw data, male participants were found to prolong both /s/ and /z/ for significantly longer durations than female participants.

The s/z ratio obtained during the 10 experimental trials was approximately 1.0 for both genders (Table 3), with /s/ being held slightly longer than /z/, as evidenced by an s/z ratio in excess of 1.0. An ANOVA on s/z ratio for men compared with women revealed no significant differences between the two genders ($F = 0.526, P = 0.473$). However, as with the maximum /s/ and /z/ prolongations, large intersubject differences could be observed for both groups. In this vocally normal population, s/z ratios varied from 0.48 to 1.36.

The trial at which subjects typically reached their absolute longest duration was trial number seven (Table 4). This held true regardless of phoneme or gender. However, it should be noted that out of the 800 trials performed by the 40 subjects, 20 instances existed (10 for /s/ and 10 for /z/), in which maximum phonation time was not reached until the tenth trial. This suggests the possibility that more trials may have been necessary to allow these subjects to reach their maximum performance, and that the average trial for attainment of MPT may have been higher than 7.

These results were determined by using the absolute longest /s/ and absolute longest /z/ prolongations out of 10 trials as the basis for determining MPT and the s/z ratio. However, research cited earlier in this paper was not usually based on the longest duration from 10 trials. For example, Eckel and Boone took the longest of two trials, and numerous investigators have used the longest of three trials. Rastatter and Hyman used the average of five trials. Thus, two additional types of /s/ and /z/ measures were created: (1) the

<p>| TABLE 1. Maximum Phonation Duration in Seconds (Out of 10 Trials) for the /s/ and /z/ Phonemes for Men (N = 20) and Women (N = 20) |
|--------------------|------|--------------------|----------------|-------------------|</p>
<table>
<thead>
<tr>
<th>Phoneme</th>
<th>Gender</th>
<th>Mean (s)</th>
<th>SD (s)</th>
<th>Range (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>/s/</td>
<td>M</td>
<td>38.28</td>
<td>14.72</td>
<td>19.60–71.20</td>
</tr>
<tr>
<td>/z/</td>
<td>M</td>
<td>37.58</td>
<td>10.52</td>
<td>21.20–53.70</td>
</tr>
<tr>
<td>/s/</td>
<td>F</td>
<td>25.68</td>
<td>7.48</td>
<td>12.00–41.10</td>
</tr>
<tr>
<td>/z/</td>
<td>F</td>
<td>24.44</td>
<td>5.15</td>
<td>14.70–38.70</td>
</tr>
</tbody>
</table>

Note: Out of the 10 trials produced by each subject for each phoneme, only the longest was used for comparison and analysis.

| TABLE 2. ANOVA for Maximum Phonation Duration (Out of 10 Trials) of /s/ and /z/ |
|------------------------|-------|------------------|---------|--------|
| Source | Sum of Squares | df | Mean Square | F Ratio | P |
| Gender | 3315.312 | 1 | 3315.312 | 18.09 | 0.000 |
| Error | 6697.893 | 38 | 176.260 | | |
| Phoneme | 18.818 | 1 | 18.818 | 0.657 | 0.423 |
| Gender x phoneme | 1.458 | 1 | 1.458 | 0.051 | 0.823 |
| Error | 1088.734 | 38 | 28.651 | | |

Note: Out of the 10 trials produced by each subject for each phoneme, only the longest was used for comparison and analysis.
maximum durations and s/z ratios based on the longest of the first three productions of each phoneme, and (2) maximum durations and s/z ratios based on an average of the first three productions of /s/ and /z/. These measures were included because they could potentially be used in a clinical setting, where many trials are often not possible to obtain.

Duration and s/z ratio data: maximum of three trials

Maximum /s/ and /z/ durations taken from the first three trials can be seen in Table 5. Values on this table represent the longest duration of /s/ and of /z/ produced by each subject among the first three trials. The results of the maximum duration task revealed similar durations for /s/ and /z/ for both male subjects (29.12 s for /s/, 31.82 s for /z/) and female subjects (19.49 s for /s/, 19.97 s for /z/), with men again producing considerably longer durations of both phonemes than women. Again, large ranges for each gender and phoneme combination were observed, which indicated a large degree of intersubject variability; and the phoneme /s/ seemed to have more intersubject variability than /z/.

An ANOVA for duration as a function of gender and phoneme can be seen in Table 6. As expected, only the main effect for gender was significant, with men prolonging both phonemes significantly longer than women.

The s/z ratio based on the maximum duration from the first three productions was approximately 1.0 for both genders (Table 7), although in this case, /z/ was held slightly longer than /s/, as evidenced by a mean s/z ratio below 1.0 for both men and women. The difference in s/z ratio when the longest of 10 trials was used versus when the longest of three trials was used suggests that the number of trials elicited can have an important effect on this measure.

An ANOVA on s/z ratio for men compared with women revealed no significant differences between the two genders (F = 0.796, P = 0.378). However, as with the previous analysis, large intersubject differences could be observed for both groups. In this vocally normal population, s/z ratios based on the longest of the first three trials varied from approximately 0.48 to 1.50.

### Table 3. s/z Ratios Based on Maximum Phonation Duration in Seconds (Out of 10 Trials) Men (N = 20) and Women (N = 20)

<table>
<thead>
<tr>
<th>Gender</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>1.01</td>
<td>0.20</td>
<td>0.64–1.34</td>
</tr>
<tr>
<td>F</td>
<td>1.06</td>
<td>0.27</td>
<td>0.48–1.36</td>
</tr>
</tbody>
</table>

Note: Out of the 10 trials produced by each subject for each phoneme, only the longest was used for the s/z ratio.

### Table 4. Average Trial Number (Out of 10) at Which the Absolute Longest Duration Was Obtained

<table>
<thead>
<tr>
<th>Phoneme</th>
<th>Gender</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>/s/</td>
<td></td>
<td>7.00</td>
<td>7.15</td>
</tr>
<tr>
<td>/z/</td>
<td></td>
<td>7.05</td>
<td>7.10</td>
</tr>
</tbody>
</table>

### Table 5. Maximum Phonation Duration in Seconds (Out of Three Trials) for the /s/ and /z/ Phonemes for Men (N = 20) and Women (N = 20)

<table>
<thead>
<tr>
<th>Phoneme</th>
<th>Gender</th>
<th>Mean (s)</th>
<th>SD (s)</th>
<th>Range (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>/s/</td>
<td>M</td>
<td>29.12</td>
<td>12.86</td>
<td>11.40–56.10</td>
</tr>
<tr>
<td>/z/</td>
<td>M</td>
<td>31.82</td>
<td>10.17</td>
<td>16.70–53.70</td>
</tr>
<tr>
<td>/s/</td>
<td>F</td>
<td>19.48</td>
<td>6.55</td>
<td>9.40–30.40</td>
</tr>
<tr>
<td>/z/</td>
<td>F</td>
<td>19.97</td>
<td>4.21</td>
<td>13.10–29.00</td>
</tr>
</tbody>
</table>

Note: Out of the first three trials produced by each subject for each phoneme, the longest was used for comparison and analysis.

### Table 6. ANOVA for Maximum Phonation Duration (Out of Three Trials) of /s/ and /z/

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F Ratio</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>2305.878</td>
<td>1</td>
<td>2305.878</td>
<td>16.031</td>
<td>0.000</td>
</tr>
<tr>
<td>Error</td>
<td>5466.016</td>
<td>38</td>
<td>143.843</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phoneme</td>
<td>50.721</td>
<td>1</td>
<td>50.721</td>
<td>2.427</td>
<td>0.128</td>
</tr>
<tr>
<td>Gender × phoneme</td>
<td>24.531</td>
<td>1</td>
<td>24.531</td>
<td>1.174</td>
<td>0.285</td>
</tr>
<tr>
<td>Error</td>
<td>794.023</td>
<td>38</td>
<td>20.895</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Out of the first three trials produced by each subject for each phoneme, the longest was used for calculating the s/z ratio.

TABLE 7. s/z Ratios Based on Maximum Phonation Duration in Seconds (Out of Three Trials) for Men (N = 20) and Women (N = 20)

<table>
<thead>
<tr>
<th>Gender</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>0.90</td>
<td>0.25</td>
<td>0.48–1.50</td>
</tr>
<tr>
<td>F</td>
<td>0.98</td>
<td>0.26</td>
<td>0.54–1.41</td>
</tr>
</tbody>
</table>

Note: Out of the first three trials produced by each subject for each phoneme, the longest was used for calculation of the s/z ratio.

Duration and s/z ratio data: average of three trials

Results of prolongation durations based on the average of the first three productions can be seen in Table 8. These durations appeared slightly shorter than those observed when we used the longest of the first three prolongations for the analysis. An ANOVA for duration as a function of gender and phoneme can be seen in Table 9. As in the previous analyses, the durations of the men were significantly longer than those of the women, but no other contrasts were significant. Again, the s/z ratio approximated 1 (Table 10), but as in the last analysis, the s/z ratios for men and women of less than 1.0 indicated that /z/ had the longer duration compared with /s/. The s/z ratio varied between approximately 0.46 and 1.57. An ANOVA on s/z ratio for men compared with women revealed no significant differences between the two genders ($F = 0.579, P = 0.451$). Like the previous analyses, large intersubject differences could be observed for both groups.

TABLE 8. Maximum Phonation Duration in Seconds (Based on an Average of Three Trials) for the /s/ and /z/ Phonemes for Men (N = 20) and Women (N = 20)

<table>
<thead>
<tr>
<th>Phoneme</th>
<th>Gender</th>
<th>Mean (s)</th>
<th>SD (s)</th>
<th>Range (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>/s/</td>
<td>M</td>
<td>25.04</td>
<td>10.10</td>
<td>9.18–43.77</td>
</tr>
<tr>
<td>/z/</td>
<td>M</td>
<td>27.33</td>
<td>8.07</td>
<td>15.43–41.23</td>
</tr>
<tr>
<td>/s/</td>
<td>F</td>
<td>16.92</td>
<td>5.46</td>
<td>9.13–29.07</td>
</tr>
<tr>
<td>/z/</td>
<td>F</td>
<td>17.47</td>
<td>3.86</td>
<td>11.67–26.17</td>
</tr>
</tbody>
</table>

Note: The first three maximum prolongation trials produced by each subject for each phoneme were recorded and averaged to provide the data above.

TABLE 9. ANOVA for Maximum Phonation Duration (Based on an Average of Three Trials) for /s/ and /z/

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F Ratio</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>1617.301</td>
<td>1</td>
<td>1617.301</td>
<td>17.954</td>
<td>0.000</td>
</tr>
<tr>
<td>Error</td>
<td>3423.137</td>
<td>38</td>
<td>90.083</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phoneme</td>
<td>40.413</td>
<td>1</td>
<td>40.413</td>
<td>2.547</td>
<td>0.119</td>
</tr>
<tr>
<td>Gender × phoneme</td>
<td>15.307</td>
<td>1</td>
<td>15.307</td>
<td>0.965</td>
<td>0.332</td>
</tr>
<tr>
<td>Error</td>
<td>603.003</td>
<td>38</td>
<td>15.868</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: The first three maximum prolongation trials produced by each subject for each phoneme were recorded and averaged to provide the data above.

Comparisons among the three calculation methods

To determine whether there were significant differences in s/z ratio based on method of calculation (based on the longest of 10 trials, on the longest of 3 trials, or on an average of 3 trials), a repeated measures ANOVA was performed, with gender as the between-subjects factors. Results can be seen in Table 11. It seemed that the calculation method did significantly affect the s/z ratio. Post hoc testing revealed that use of the maximum /s/ and /z/ prolongations from among 10 trials produced significantly different results than the use of /s/ and /z/ prolongations from either the longest of the first three productions or an average of the first three productions. Examination of s/z ratios from Tables 3, 7, and 10 show that when the s/z ratio is based on the maximum prolongations out of 10 trials, then /s/ is held for slightly longer than /z/ (as indicated by an s/z ratio in excess of 1). In contrast, when the s/z ratio is based on either maximum prolongations out of 3 trials, or on an average of the first 3 trials, then /z/ tends to be held for a longer

TABLE 10. s/z Ratio Based on an Average of Three Trials for /s/ and /z/

<table>
<thead>
<tr>
<th>Gender</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>0.91</td>
<td>0.25</td>
<td>0.46–1.36</td>
</tr>
<tr>
<td>F</td>
<td>0.97</td>
<td>0.25</td>
<td>0.55–1.57</td>
</tr>
</tbody>
</table>

Note: The first three maximum prolongation trials produced by each subject for each phoneme were recorded and averaged to provide the data above for men (N = 20) and women (N = 20).
Individual data

Individual data for s/z ratio did not always approximate the means given in Tables 3, 7, and 10. In fact, on the basis of absolute longest /s/ and /z/ production out of 10 trials, 11 subjects had longer /z/ productions, 22 subjects had longer /s/ productions, and only 7 subjects produced similar durations for the /s/ and /z/ phonemes, as predicted by Eckel and Boone. If the longest of the first three trials was the basis of calculation, 23 subjects had longer /z/ productions, 15 had longer /s/ productions, and only two had approximately equal-duration productions of /s/ and /z/. Table 12 displays the aggregate data for several typical subjects in each category.

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F Ratio</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>0.038</td>
<td>1</td>
<td>0.038</td>
<td>0.758</td>
<td>0.390</td>
</tr>
<tr>
<td>Error</td>
<td>1.925</td>
<td>38</td>
<td>0.051</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Method</td>
<td>0.249</td>
<td>2</td>
<td>0.124</td>
<td>8.137</td>
<td>0.001</td>
</tr>
<tr>
<td>Gender × method</td>
<td>0.002</td>
<td>2</td>
<td>0.001</td>
<td>0.050</td>
<td>0.951</td>
</tr>
<tr>
<td>Error</td>
<td>1.610</td>
<td>76</td>
<td>0.015</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Subjects included both men (N = 20) and women (N = 20).

DISCUSSION

The purpose of this study was to investigate some assumptions underlying the s/z ratio, specifically the assertion that in subjects with normal vocal fold function, /s/ and /z/ should be maximally prolonged for approximately similar durations. It was hypothesized that for valid results, intensity should be controlled when eliciting /s/ and /z/ productions, because different intensity levels for the two phonemes could require varying degrees of respiratory effort, vocal effort, and/or laryngeal/airway resistance, which could in turn affect maximum phonation time.

The first research question, do maximally prolonged /s/ and /z/ produced with controlled intensity have similar durations, was answered yes, at least for data averaged over all subjects. When the longest durations of /s/ and /z/ based on either 10 trials or 3 trials were analyzed, results showed no significant differences between the two phonemes. However, significant differences were found between male and female subjects, with male subjects prolonging the two sounds for significantly greater amounts of time. No significant gender x phoneme interaction was
found. Similar results were obtained when /s/ and /z/ durations were calculated based on an average of three productions.

When the data were examined in more detail, however, the similarity of /s/ and /z/ duration seemed to be an artifact of group averaging. The prolongations of a specific subject usually showed a pattern of either /s/ being held longer than /z/ or /z/ being held longer than /s/. These differences seemed to average out over the data set, which resulted in apparently equal durations of /s/ and /z/. However, out of 40 subjects, only 11 subjects produced approximately equal durations of /s/ and /z/ when the longest of 10 trials was used; and only 2 subjects produced approximately equal durations of /s/ and /z/ when the longest of 3 trials was used.

The second research questions addressed differences in s/z ratio between men and women. Results showed that s/z ratio did not vary as a function of gender. This finding held true whether s/z ratio was calculated on the basis of the longest prolongations of 10 trials, the longest of 3 trials, or the average of the first three prolongations of each phoneme.

The results obtained in this study are in agreement with the findings of Eckel and Boone, and at least one of the Soman trials for adults with healthy larynges. Eckel and Boone found approximately equal maximum prolongation durations of /s/ and /z/ with no significant differences between the two, and an s/z ratio approximating one (s/z = 0.99). A similar result was obtained by Soman in her “verbal instructions only” condition (s/z = 0.91), although in other conditions, she found s/z ratios from 1.17 to 1.37. The current finding of s/z ratios approximating one is consistent with Eckel and Boone and to some degree with Soman. However, the current finding of a range of s/z ratios of approximately 0.46 to 1.57 in healthy persons is inconsistent with the recommendation of Eckel and Boone that s/z ratios in excess of 1.4 may be considered abnormal.

The results of this study suggest that clinical application of the s/z ratio should be undertaken with caution. Even with careful instruction and demonstration, subjects took an average of 7 trials to reach their maximum performance, and some seemed to be capable of improving beyond the 10 trials elicited in the experimental protocol. Such a large number of trials may be too time-consuming and too likely to induce fatigue to be practical in a clinical setting. Furthermore, practice appeared to differentially affect /s/ and /z/. When only the first three trials were analyzed, more than half of the subjects produced longer /z/ durations than /s/ durations, and in fact the mean s/z ratio was slightly below 1. However, when all 10 trials were analyzed, more than half of the subjects produced longer /s/ than /z/ durations, and mean s/z ratio was slightly above 1. This reversal suggests that somewhere between the third trial and the tenth trial, subjects “learned” more efficient ways of producing or prolonging /s/.

What could account for the earlier superiority of /z/ and the need for practice on /s/? In producing /s/, acoustic energy comes exclusively from the turbulence/noise generated at the articulatory valve (tongue tip against the alveolar ridge). By contrast, acoustic energy for /z/ comes from both vocal fold vibration at the laryngeal valve and the noise generated at the articulatory valve. Compared with noise, a voiced signal might more efficiently convert aerodynamic energy to acoustic energy, and thus it may be easier for some subjects to produce particularly if a specific intensity level is required. However, experimentation with such variables as tongue tension and positioning over several trials may eventually result in improved performance on /s/ prolongations, especially with motivated subjects. Furthermore, different subjects may bring different strengths and weaknesses to the phoneme prolongation task, which may account for the large intersubject variability observed in this study.

An element that continues to be missing in discussions of s/z ratio is the relationship of airflow to duration. As suggested by Tait et al, maximum durations of /z/ may exceed maximum durations of /s/ because of “conservation in air flow because of laryngeal valving.” Although it would explain why a certain number of subjects typically prolong /z/ longer than /s/, what about subjects who prolong /s/ longer than /z/? And what about the underlying assumption of the s/z ratio that similar airway configurations and driving pressures should cause /s/ and /z/ to be prolonged for similar amounts of time? Assuming intensity (and thus vocal effort) is held constant, does airflow play a role in prolongation
duration for one or both phonemes? Further research on s/z ratio must examine the relationship between phoneme duration, intensity, and airflow to determine whether the theoretical basis of the s/z ratio is in fact valid.

REFERENCES