# THE PRIMARY ARTICULATION OF PLAIN-EMPHATIC /S/-/Sˤ/ IN LEBANESE ARABIC: AN EMA STUDY

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## ABSTRACT

The phonemic inventory of Arabic includes a plain-emphatic contrast in a number of coronal stops and fricatives. The emphatic members in these contrastive pairs are articulated with a secondary posterior constriction in the velopharyngeal region of the vocal tract. This secondary constriction is absent in the plain counterparts. The primary constriction is also believed to differ in the plain-emphatic pairs. This study examines the differences in the primary articulation of the plain-emphatic voiceless alveolar fricatives /s/-/sˤ/ in Lebanese Arabic as reflected in the configuration of the tongue blade. Findings suggest that the tongue blade is lower during /sˤ/ than during /s/. There is also evidence for tongue blade concavity during /sˤ/, a configuration not assumed during /s/.

**Keywords**: electromagnetic articulography, emphatics, Arabic, fricatives

## 1. INTRODUCTION

The phonemic inventory of Arabic includes a set of *emphatic* coronals that are phonemically contrastive with their *plain* counterparts. The term *emphatic* refers to a quality of the speech sound that results from a posterior constriction in the velopharyngeal region of the vocal tract [6][10]. This secondary constriction is absent in the plain counterpart. The quality of the resulting emphatic speech sound has been described as "heavy", "dull", and "dark" [13]. The primary constriction is also believed to differ in the plain-emphatic pair [9]. While many articulatory studies have focused on describing the secondary articulation of emphatics [7] [12], this work compares the primary articulation of a plain-emphatic contrast. The object of this study is the plain-emphatic voiceless alveolar fricatives /s/-/sˤ/ in Lebanese Arabic.

Previous acoustic studies of emphatics in Arabic reported the raising of F1 and lowering of F2 in adjacent vowels [1] [7]. This is in line with predictions made by Perturbation Theory [4]. In the framework of Perturbation Theory, the velopharyngeal region is modelled as a node (a point of maximum pressure) in the standing wave of F1, and an anti-node (a point of maximum velocity) in the standing wave of F2. Perturbation Theory predicts an increase in the resonant frequency when a constriction occurs at a node, and a decrease in the resonant frequency when a constriction occurs at an anti-node [8]. Al-Tamimi & Heselwood [1] used nasoendoscopy to compare the articulation of plain-emphatic sounds of Arabic. They observed epiglottal retraction and an inward movement of the rear and lateral pharyngeal walls during emphatics. They also conducted a videofluoroscopy study that pointed to an enlarged buccal (mouth) chamber during emphasis. Zeroual et. al. [15] conducted an Electromagnetic Articulography (EMA) study to examine the place of constriction in the plain-emphatic pairs /t/-/tˤ/ and /d/-/dˤ/ in Moroccan Arabic. Their study found that plain members are articulated with a more laminal contact than the emphatic counterparts, while emphatic members are more apical. They also reported slight labialization during the emphatic members. While the object of study in [15] was plain-emphatic stops in Moroccan Arabic, the current study examines the plain-emphatic voiceless alveolar fricative contrast in Lebanese Arabic.

## 2. METHODOLOGY

Data was collected from three male graduate students at the University of Illinois at Urbana-Champaign. Each participant is a native speaker of Lebanese Arabic from Beirut, which controls for dialectal differences that exist in different parts of Lebanon. All speakers confirmed a negative history for speech and hearing-related impairments. Data collection was conducted in the NeuroSpeech Lab in the Department of Speech and Hearing Science at the University of Illinois, using the WAVE electromagnetic articulograph (Northern Digital Inc., Waterloo, Ontario, Canada). This system generates an electromagnetic field around the head of the participant. Nine disposable self-calibrating sensors were glued or taped to the orofacial articulators of interest as follows:

- Three sensors were placed along the midline of the tongue. The first, tongue front (TF), was placed at a distance of approximately 1 cm back from the tongue tip on the midline of the tongue. The second, tongue middle (TM), was placed approximately 1 cm behind TF. The third, tongue back (TB) was the most posterior sensor in the tongue and was placed approximately 1 cm behind TM.

- Two reference sensors were placed side by side on the relatively immobile zygomatic process.
- One sensor was placed on the nose bridge.

In addition, two sensors were placed on the vermilion border of the upper and lower lips, and one sensor on the chin. Analysis of data collected from these last three sensors is not included in this study. Three additional sensors were attached to a bite plate to determine the participant's occlusal plane. The speaker was instructed to read sentences displayed on a computer screen. The WAVE system tracks the positions of the sensors in three-dimensional space at a rate of 100 samples per seconds. The stimuli presented to the participant consisted of sentences containing 36 minimal triplets that are contrastive in the three voiceless alveolar and postalveolar fricatives of Arabic: emphatic alveolar /sˤ/, plain alveolar /s/, and postalveolar /ʃ/. For the first speaker, all words were embedded in the carrier phrase of Lebanese Arabic: "ʔuːluː X marra taːnje" ('say X again'). For the second and third speakers, the carrier phrase was: "ʔallaː X ʔaktar min marra" ('he said X to her more than once'). The carrier phrase was presented in Lebanese Arabic to ensure that the speaker articulated the target word in his dialect. Care was taken to select target words that are real words of Arabic – mostly Lebanese Arabic. In each triplet, at least two words were real words. The voiceless fricative of interest occurred in varied phonological contexts: word-initial, word-final, and word-medial, surrounded by various vowels (/u/, /i/, /e/, and /a/) and consonants. Two repetitions of each triplet were recorded, for a total of 36 triplets × 3 test items in each triplet × 2 repetitions = 216 tokens from each speaker. Table 1 shows examples of some of the triplets in this study.

**Table 1**: Examples of some of the /sˤ/-/s/-/ʃ/ minimal triplets in this study.

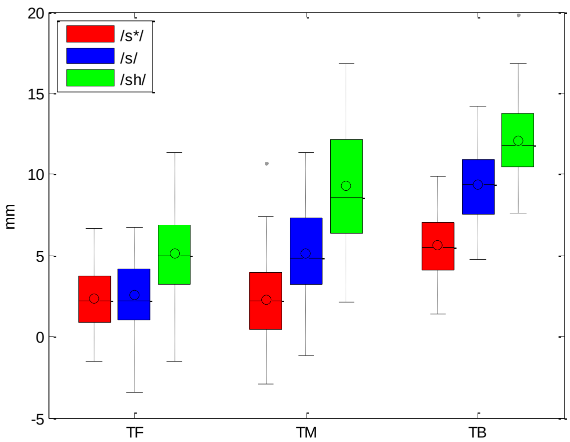
| Word | IPA | Gloss |
|---|---|---|
| صين | sˤiːn | China |
| سين | siːn | the letter name for /s/ in Arabic |
| شين | ʃiːn | the letter name for /ʃ/ in Arabic |
| نَصَّف | nasˤsˤif | he divided in half |
| نَسَّف | nassif | he detonated (a bomb) |
| نَشَّف | naʃʃif | he dried (wiped off) something |

In addition to position data, acoustic data was recorded simultaneously using a Countryman Isomax E6 head-mounted microphone. The acoustic data was annotated in Praat [3] to extract the start and end times of the fricatives of interest. A low-pass Butterworth filter with a cutoff frequency of 15 Hz was applied to the position data. The position data was then rotated and translated to correct for head movement at each speaker's occlusal plane.

## 3. RESULTS

The start and end times of the fricative identified from the acoustics were used to extract the position data that corresponded to the fricative. We then tested whether the tongue blade is lower during /sˤ/ than during /s/ as per our hypothesis. This is indicated by lower y-coordinate values of TF, TM and TB during /sˤ/ than during /s/. While the objects of this study are the fricatives /sˤ/ and /s/, data from these two fricatives were compared against data for /ʃ/ in order to visually assess the magnitude of difference between the emphatic-plain pair. The minimum vertical position of the tongue sensor for each fricative in each token was taken to be representative of the vertical position during the fricative. Box plots [2] are shown in Figures 1, 2, and 3 to illustrate the difference in vertical displacement (in mm) across the three fricatives at points TF, TM, and TB for speakers 1, 2, and 3 respectively. The mean vertical position is represented by a circle in the box, and the median by a black bar.

**Figure 1**: Box plots of the distribution of the minimum vertical displacement at points TF, TM, and TB in /s/, /sˤ/ (s*) and /ʃ/ (sh) for speaker 1.




A two-tailed paired t-test was used to test for differences in tongue elevation. The differences in vertical position at both points TM and TB for /sˤ/ and /s/ were statistically significant at $p < 0.001$ and degrees of freedom df = 71 for all three speakers after applying a Bonferroni correction (at TM: t = 10.79, 6.01, and 7.79 and at TB: t = 14.29, 9.99, 10.75 for the three speakers respectively. Differences at point TF for the three speakers were not statistically significant (t = 1.49, 2.58, and 0.66).

**Figure 2**: Results for speaker 2. Conventions as in Figure 1.

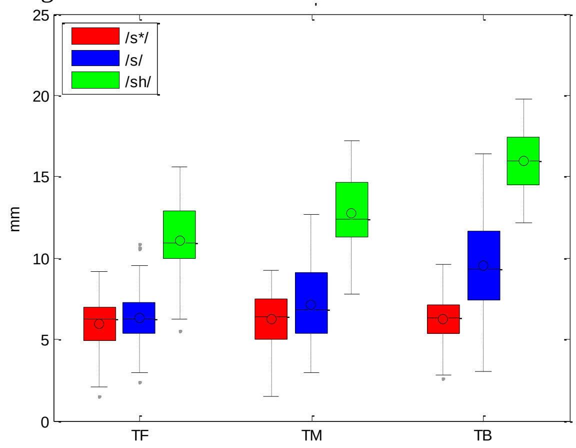
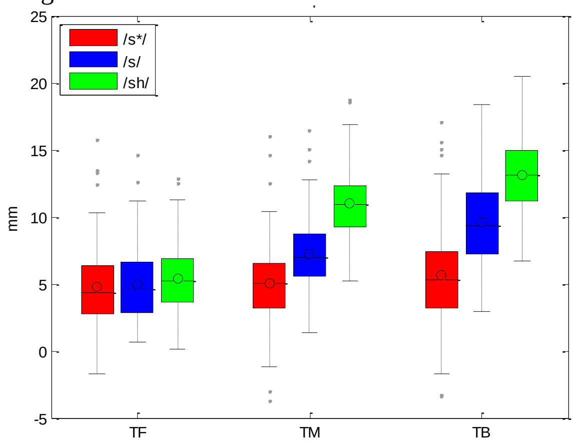



**Figure 3**: Results for speaker 3. Conventions as in Figure 1.




Another measure used to test the significance of the difference in the vertical position of TF, TM and TB was the Cartesian distance to determine whether clusters of data points are distinct. Representative data of this measure are presented for speaker 1 in Figure 4. Figure 4 shows scatter plots of the xy Cartesian coordinates of the three points TF, TM, and TB. The top, middle, and bottom plot show data for TF, TM, and TB respectively. In each plot, data for /sˤ/ are shown in red; data for /s/ in blue; and data for /ʃ/ in green, and the two repetitions of each test item are averaged. A least squares method [5] was used to fit an ellipse to each set of data points. Cartesian distances were computed between each /sˤ/ data point and the center of the /sˤ/ ellipse. Another set of Cartesian distances were computed between each /sˤ/ data point and the /s/ ellipse. Comparable distances in the two sets is indication that the /sˤ/ and /s/ data points do not form two distinct clusters.

In contrast, statistically significant differences between the two sets of distances suggest that the two clusters are distinct. A two-tailed t-test was performed between the two sets of distances, and a *p*-value was computed and adjusted using a Bonferroni correction. This was done for the TF, TM, and TB data. Results indicated statistically significant differences in distances at $p < 0.001$ and df = 35 for the TM and TB data for speakers 1 and 3, and for the TB data for speaker 2 (at TM: t = 5.2, 0.69, and 11.48 and at TB: t = 10.89, 6.82, and 9.44 for the three speakers respectively). This suggested that the two position clusters for /sˤ/ and /s/ were distinct at TM and TB for speakers 1 and 3, and at TB for speaker 2. Results for the TF data were not statistically significant for two of the three speakers (at TF: t = 0.56, 4.08, and 0.64 for the three speakers respectively). Measuring distances between the centers of fitted ellipses to determine the relative location of a distinct lingual target with another has been implemented in previous studies such as [14].

In addition, a smoothing spline ANOVA (SSANOVA) [11] was carried out to understand differences in the contours of the three fricatives. Results for speaker 1 are plotted in Figure 5. Distinct tongue contour shapes for /sˤ/ and /s/ are evident. In the regions where the confidence intervals of the two fricatives do not overlap (the dashed lines around the contour), it can be asserted with 95% confidence that the tongue position is different for both fricatives. The concave tongue contour of /sˤ/ is evident in the figure. Slight concavity was also observed in the SSANOVA plot of the third speaker, but not that of the second speaker.

## 4. DISCUSSION

The box plots in Figures 1, 2, and 3 show that the vertical positions of TM and TB are lower during /sˤ/ than during /s/. This result was found to be statistically significant at $p < 0.05$ for all speakers. There were no statistically significant differences in the vertical positions of TF. This last result suggests that the front of the tongue at TF in both /sˤ/ and /s/ remains low behind the front teeth, while the points further back on the tongue at TM and TB are lowered during /sˤ/, possibly creating a hollow that is not present during /s/. The SSANOVA results in Figure 5 further corroborate this description. It is evident in this plot that the tongue contours at TF for /sˤ/ and /s/ are at approximately the same elevation and that their confidence intervals intersect. This is not the case for the tongue contour of /ʃ/ at TF which is more elevated. This is expected as the articulation of /ʃ/ involves a slightly raised tongue front which creates a sublingual cavity. The tongue contour of /sˤ/ at TM and TB is lower than that of /s/. A distinct concave shape is also evident for the contour of /sˤ/, a shape not assumed by the contour of /s/. The contour of /ʃ/ at TM and TB is more elevated than both the contours of /sˤ/ and /s/. This observation is expected as, by definition, the articulation of post-alveolar /ʃ/ involves the blade of the tongue coming into close contact at the border of the alveolar ridge and the palate to form a constriction. This area

**Figure 4**: Scatter plots of averaged xy coordinates from two repetitions during /s/, /sˤ/ (s*), and /ʃ/ (sh) at points TF, TM, and TB for speaker 1[1]. Least squares ellipses are fitted to the data from each fricative.

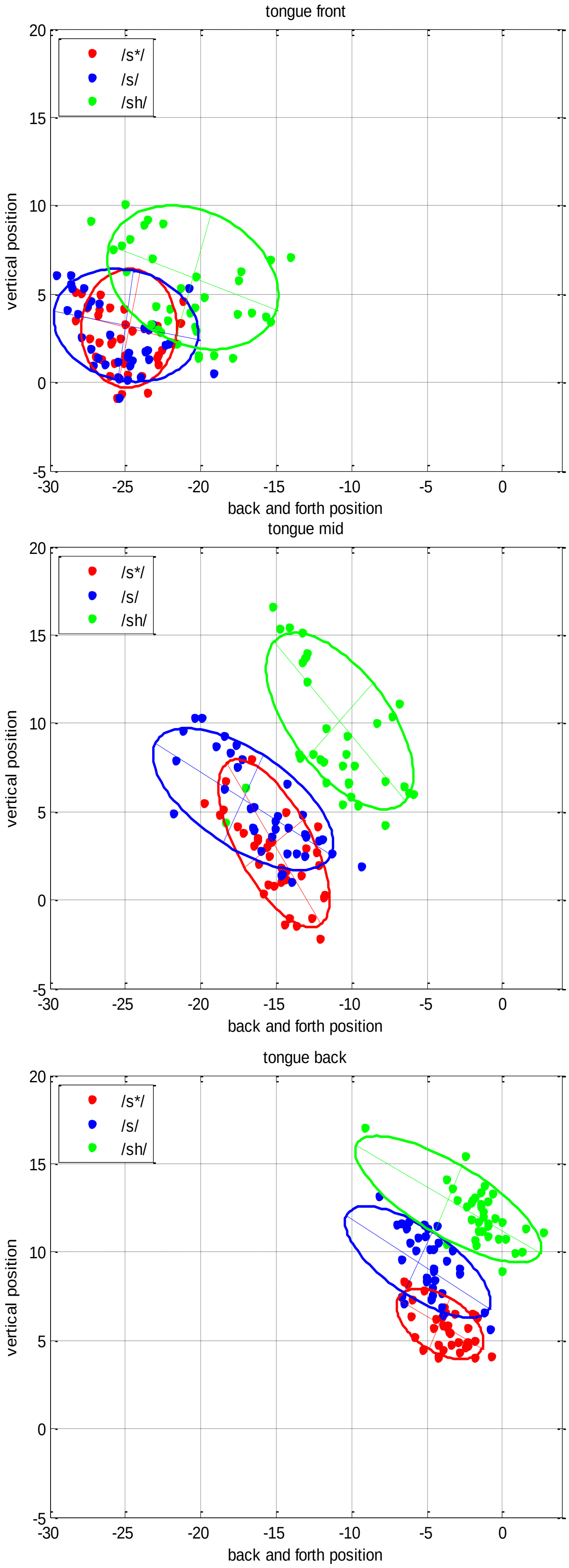
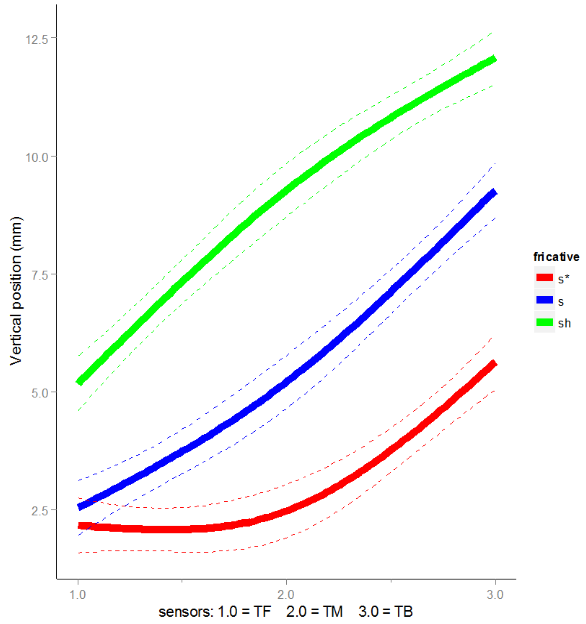



**Figure 5**: Smoothing Spline ANOVA for position data at points TF, TM, and TB approximating the tongue contours for /s/, /sˤ/ (s*), and /ʃ/ (sh) between these points for speaker 1.




of the tongue blade corresponds to points TM and TB. Results from Figure 4 also support this analysis. In the scatter plot for TF, results show that differences between the /sˤ/ and /s/ clusters are not significant, suggesting that the position of TF is the same during /sˤ/ and /s/. We can see that the cluster for /ʃ/ is distinct and occupies a more elevated position, confirming that the front of the tongue during /ʃ/ is slightly raised, to form the sublingual cavity. In the plot for TB, the results suggest that the differences between the /sˤ/ and /s/ clusters are statistically significant in all speakers. The differences between the /sˤ/ and /s/ clusters are also statistically significant in the TM data for speaker 1. This indicates that the position of the tongue at those points during /sˤ/ is lower than during /s/.

## 5. CONCLUSION

The purpose of this EMA study was to understand the differences in the primary articulation of the plain-emphatic voiceless alveolar fricatives /s/-/sˤ/ of Lebanese Arabic as demonstrated by the configuration of the tongue blade. The results suggest that the front of the tongue, up to 1 cm from the tongue tip, remains low behind the front teeth in approximately the same position in both /sˤ/ and /s/. Points further back on the tongue, up to 3 cm behind the tongue tip, are lower during /sˤ/ than /s/. There is also evidence for tongue concavity during the emphatic member /sˤ/ in at least two of the three speakers in this study, a shape not assumed during the plain counterpart /s/.

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[1] Two outlier points were removed from the /ʃ/ data at TM when fitting the /ʃ/ ellipse.