Stability of Locus Equations with Error and Vowel Removal

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ABSTRACT

The Locus Equation (L-E) yields a slope as an acoustic measure of coarticulation. Effects on the slope of introducing varying amounts of error in the F_2 Hz values in L-Es and the results of using fewer than ten vowels were investigated. Seventy-five sets of 20 F_2 measurements were used for derive 2000 sets for each of the initial consonants /b/, /d/, and /g/ using Monte Carlo techniques. Slopes of the sets were altered with 50, 100, or 200 Hz error being randomly applied to each F_2 value. Then selected vowels were removed from the sets and the effects on the slopes were measured. Finally, the effects of error and fewer vowels were obtained. Results suggest that the L-E slopes are resistant to error and reduced number of vowels. Effects of adding 50 or 100 Hz of random error to the F2 values in each set were minimal, yielding a mean absolute change in slope of approximately 0.07. Slopes based on six, eight or ten vowels were judged to not be substantially different, and were not affected by 50 or 100 Hz random error, based on a standard of an absolute mean change in slope of <0.10 . Nomographs are provided to facilitate the design of L-E studies.

INTRODUCTION

During speech production a series of abstract phonemes is turned into an overlapping string of motor gestures. The overlapping process, known as coarticulation, has been recognized as a crucial part of fluent speech production and has been widely studied (Kent and Minifie, 1977; Kunert and Nolan, 1999).

Coarticulation, however, has proven difficult to study requiring surface or hooked-wire electrodes (Abbs and Watkin, 1976), mechanical levers (Barlow & Abbs, 1983), x-ray tracking of lead pellets (Borden & Gay, 1978; Perkell & Nelson, 1981) or other invasive techniques which are hard to apply to clinical populations or typically-developing children. Because of these difficulties a method for measuring coarticulation through the analysis of its acoustic results/effects has been developed. This method known as the locus equation (L-E) approach was based on work by Lindblom (1963) and refined by Sussman & colleagues.

The L-E is designed to measure the anticipatory effect of the vowel on the initial consonant in CVC words. The initial consonants /b, d, g/ are widely used, typically with ten vowels in consonant-vowel-consonant syllables (CVCs). The word "locus" comes from the earlier concept of consonants having an acoustic location in the frequency of the second formant (F_2) associated with onset of the consonant, regardless of the vowels as seen in speech spectrography (Delattre, Liberman, and Cooper, 1955; Potter, Kopp, and Green, 1947; Lindblom 1963).
This is notable especially for the /d/-V-C series where the F_2 appears in the region of 1800 Hz (in adult males) and makes a transition to the F_2 in the vowel. The F_2 of 1800 Hz is a product of the length of the vocal tract behind the alveolar point of closure for the /d/. When the /d/ is released the 1800 Hz F_2 manifests itself briefly (the F_2 onset frequency) before the vowel articulation alters it.

Thus, a plot of the onset F_2 value against the midpoint F_2 value can give an idea of the amount of anticipatory coarticulation. If the slope of the plot is near 0.0, this indicates little or no anticipatory influence. However, a slope closer to 1 indicates a greater effect from the vowel on the articulation of the consonant.

However, certain technical and practical aspects of the measurement process itself remain largely unexplored. First, F2 measurements are typically made by hand from spectrograms of recorded CVC monosyllables. This process is subject to certain unknown amounts of error. Even with modern analytic software such as PRAAT (Boersma and Weenik 2012), SpeechStation II (Senimetrics 2004), or WaveSurfer (Sjolander and Beskow 2006), among others, errors may occur for a variety of reasons. Second, the measurement process for generating locus equations for /b/, /d/, and /g/ is time consuming when ten vowels are used. Thus, it would be more efficient if reliable slopes could be obtained when fewer vowels are selected.
This study was designed to answer questions related to the stability of the L-E slopes in the presence of measurement error and reduced numbers of vowels:

Question 1. What is the effect on L-E slope when random errors of 50, 100, or 200 Hz are applied to each of the 20 F2 values in L-E sets for initial /b/, /d/, and /g/?

Question 2. What is the effect on the L-E slope when the number of vowels in the L-E set is reduced systematically from ten to three?

Question 3. What is the effect on the L-E slope when *both* random error and reduction of the number of vowels is applied to L-E sets (as above)?

METHODS

The generation of the collection of the simulated L-E sets involved three steps: First, slopes derived from L-Es using initial-/b/ , /d/, or /g/ monosyllables were collected from the studies in the literature This allowed statistical distributions of slopes to be prepared for each consonant, hereafter called *existing* slopes. Second, 75 L-E sets were generated through acoustic analysis of new recordings for each consonant, forming *new* L-E sets. Finally Monte Carlo techniques were applied to each of the new L-E sets to yield 2000 simulated, normally distributed L-E sets for each consonant.

Three experiments were conducted on the 2000 simulated L-E sets:
Experiment 1 – +/- 50, 100, and 200 Hz measurement error was added to each onset and midpoint F_2 measurement, and new L-E slopes were generated.
Experiment 2 – The number of vowels was systematically reduced from 10 to 3, with new L-E slope measure taken after each reduction.
Experiment 3 – Vowel Reduction was combined with the addition of error. The vowels were systematically reduced and error was applied, with new L-E slopes produced at each step.

RESULTS

<u>Experiment 1 – Error Addition</u>

Figure 1. The mean absolute change in the average slope with the addition of small (50 Hz), moderate (100 Hz) and large (200 Hz) amounts of error

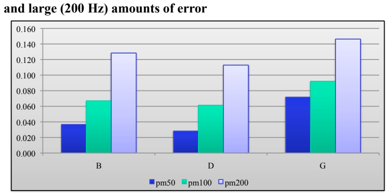
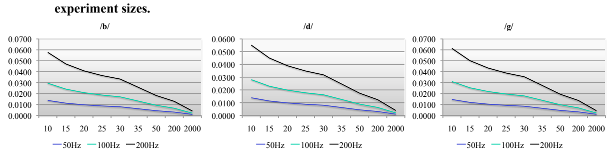
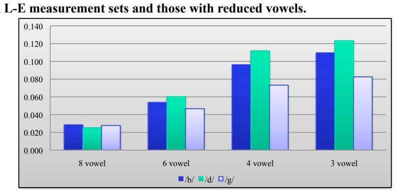


Figure 2. Nomographs showing 95% confidence intervals in slope units for each consonant when 50, 100, and 200 Hz error is added. Sample size is on the horizontal axis, representing typical L-E experiment sizes.



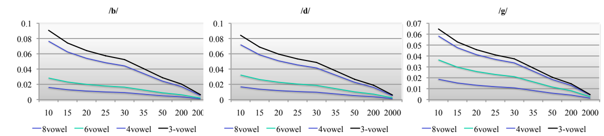
<u>Experiment 2 – Vowel Reduction</u>

Figure 3. The change in the absolute value of the difference between slopes from the canonical 10 vowel L-E measurement sets and those with reduced vowels.



RESULTS (continued)

Figure 4. Nomographs showing 95% confidence intervals for the change in slope units when vowel inventory for L-E measurement is smaller than 10 vowel canonical set. Horizontal axis shows typical sample sizes.



<u>Experiment 3 – Vowel Reduction and Error Addition</u>

Figure 5. The change in the mean absolute value of combination of the effect of selective vowel removal and addition of error on the average slope of locus equations. Change from the canonical 10 vowel set is indicated.

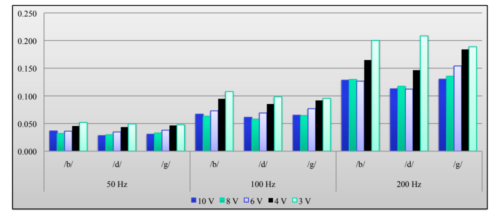
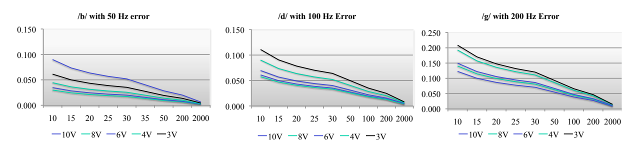


Figure 6. Example nomographs showing the expected change in absolute value of the L-E slope measure with the addition of error. Left nomograph shows /b/ with 50 Hz error, center shows /d/ with 100 Hz error, and right shows /g/ with 200 Hz error. The vertical axis shows the confidence interval in slope units, and the horizontal axis shows sample size.



CONCLUSIONS

1. This measure is stable even when subjected to small (50 Hz) and moderate (100 Hz) amounts of error, which can arise from the measurement process. With the inclusion of large (200 Hz) amounts of error, the measure begins to not be as stable. However, this amount of error is not usual or expected in any natural variation or process of measurement.
2. This study demonstrated that the L-E slope measure is stable when using vowels sets that are smaller than the canonical and traditional 10 vowel set. For vowel sets of 8 or 6, the slope measure is stable enough to still be considered a reliable predictor of stop consonant place of articulation.
3. This study showed that these smaller vowel sets are robust even with the inclusion of small and moderate amounts of error.
4. As a guide for future research, nomographs were created that can show with 95% confidence how much deviation from a 10 vowel canonical set with no error a researcher can expect in an experiment that uses a smaller vowel set and a practical sample size with the possibility of measurement error.