STATISTICAL METHODS FOR QUANTITATIVE ANALYSIS OF MULTIPLE LENITION COMPONENTS

Christina Villafaña Dalcher

City University, London
cvd1@city.ack.uk

ABSTRACT

Lenition has been described in various ways but broadly involves multiple acoustic parameters. These include closure duration, VOT duration, periodicity, intensity, and absence of release burst [9, 11]. Because these concrete acoustic characteristics are variable and sometimes independent of one another, it is difficult to quantify the more abstract construct of lenition by referring to its separate components.

This paper introduces a method of producing a quantitative measure of lenition, using a latent variable score derived via Principal Components Analysis on five individual parameters having a recognised relationship to consonant weakening.

Keywords: lenition, quantitative analysis, Gorgia Toscana, Principal Components Analysis

1. INTRODUCTION

Lenition is a widely observed sound-altering process in connected speech [5, 7, 9]. This weakening of consonants appears in a variety of languages, both diachronically and synchronically, manifesting itself variously in the subcategories of voicing, fricativization, approximantization, debuccalization, and deletion.

This weakening process is treated in various ways in the literature. Trask defines it as “any phonological process in which a segment becomes either less strongly occluded or more sonorous” [14]. Others correlate lenition with some reduction in articulation, implying that reduced effort is responsible for weakening segments [3, 7, 13]. Lavoie discusses lenition as a process by which consonants become more sonorous and less consonantal [9]. Lenition has been presented as a unidirectional progression among varying degrees of weakness, such that “a segment X is said to be weaker than a segment Y if Y goes through X on its way to zero” [6].

Only in a few recent works have we seen an attempt to quantify this rather abstract concept. Lewis identifies five acoustic parameters that may be used to objectively verify and quantify weakening: 1) closure duration (shorter closure = more lenition); 2) VOT duration (shorter VOT = more lenition); 3) percentage of closure voicing (more voicing = more lenition); 4) peak intensity (closer intensity of stop to surrounding vowels = more lenition); and 5) conservation of release burst (lack of burst = more lenition) [11].

Lavoie offers similar phonetic characteristics predictive of weakening, and also includes decreased linguopalatal contact, increased formant structure, and decreased aperiodic energy [9].

Because lenition comprises multiple, and somewhat independent, acoustic characteristics, it can be difficult to say whether a given sound is more or less lenited. The present paper attempts to resolve this problem by integrating several observable acoustic elements into an underlying quantitative variable.

2. METHODS

2.1. Data collection and measurement

The acoustic data was collected as part of a broader study of lenition in Florentine Italian [16], a process known as *Gorgia Toscana*. Six adult subjects (three females and three males), all native speakers of Florentine, participated in the study. Sentence-reading tasks resulted in a set of 660 voiceless stops (197 /p/, 232 /t/, 231 /k/), all in intervocalic contexts controlled for lexical frequency, prosodic domain, and stress. Due to the general CV syllable structure of Italian, all consonants occurred in onset position. 23 of the tokens were discarded due to disfluencies. Subjects’ speech was recorded using a Sennheiser unidirectional microphone, a USB Pre hard-disk recorder, and a Macintosh computer. Data was segmented and analyzed in Praat software [1]. Each segment was then categorized into one of six allophone groups [12] based on visual and auditory aspects of the spectrogram and waveform:

- weak approximant/deleted segment (WA)
- approximant (A)
- fricative (F)
- semi-fricative (SF)
- fricated stop (FS)
- stop (S)

To measure lenition indicators, the present study adapts the acoustic parameters of previous works [9, 11] into the following:

- Relative Constriction Duration (CD)
  ratio of constriction duration of segment to total VCV sequence duration
- Relative VOT Duration (VD)
  ratio of VOT to total VCV duration
- Relative Total Duration (TD)
  Relative Constriction Duration + Relative VOT Duration
- Relative Intensity (I)
  ratio of intensity of constriction period to intensity of utterance
- Relative Periodicity Power (PP)
  delogged harmonics to noise ratio [1]
- Release Burst Absence (BA)
  visible lack of burst in spectrogram

2.2. Indicators of lenition

The foregoing quantitative measures can only produce a standardised account of lenition if they themselves are reliable predictors of lenition. In other words, we need to establish that such measures pattern with allophonic distribution in a predictable way. Table 1 presents the dependent variable measurements by allophone for all voiceless stops.

Table 1: Dependent variables by allophone

	CD	VD	TD	I	PP	BA
WA	n/a	n/a	n/a	n/a	n/a	1.00
A	.20	.00	0.20	-4.98	.93	1.00
F	.30	.00	0.30	-13.95	.70	0.99
SF	.27	.06	0.33	-14.31	.70	1.00
FS	.18	.15	0.33	-16.03	.69	0.00
S	.21	.12	0.33	-17.80	.66	0.02

Neither constriction duration nor VOT duration on its own serves to indicate weakening in the expected way. Total duration, however, results in a much more consistent (and expected) pattern of behaviour: while there is no significant difference in duration among the three strongest allophones, weaker variants are progressively shorter.

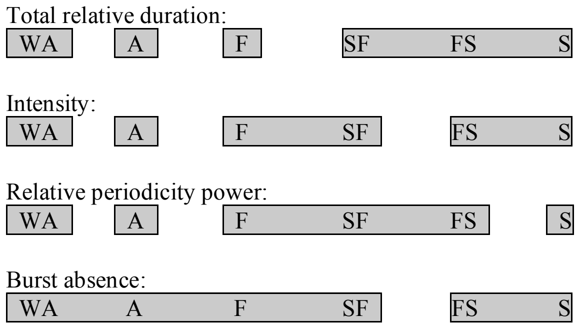
Relative intensity in terms of allophone category also meets expectations. There is a minimal contrast in the intensity of fricatives (F) and semi-fricatives (SF), likely due to the very low *N* of the latter and the fact that these two allophones are minimally different acoustically. Weak segments generally have higher intensities, however.

There is also a consistent, if not robust, relationship between weaker allophones and higher periodicity. Although the three variants exhibiting frication do not exhibit significant variation in voicing, there is a clear trend for weaker segments to increase in their periodicity-to-noise ratio.

Since burst absence is one of the factors used in classifying tokens into allophonic categories, weaker segments naturally have burst absence rates of 1 (or close to 1), while stronger segments have burst absence rates of 0.

Thus only four measurable lenition indicators reflect, with different degrees of predictive power, the surface manifestations of the voiceless stops /p,t,k/. They are: total relative duration, relative intensity, relative periodicity power, and burst absence. Fig. 1 illustrates the strength with which each measurement contrasts allophone categories.

Figure 1: Homogeneous subsets of voiceless stop allophones predicted by dependent variables.



The following section discusses latent variable extraction from these four independent measures.

3. LENITION AS A DERIVED CONSTRUCT

3.1. Latent versus observable variables

Directly observable items such as interest rates, test scores, and vocabulary size are readily measured. Abstract concepts such as economic strength, intelligence, language proficiency – all of which are frequently discussed in the social sciences – can be extremely difficult to measure. Even so, there are at least two arguments in favour of using abstract constructs in quantitative studies like the present one.

One advantage is efficiency. We can measure several variables and test hypotheses using each of them separately, but it is much easier to reduce multiple variables to one or two and subsequently run tests on the resulting smaller set.

The more important argument is focus: the present study is about lenition itself, not its particular manifestations. An ability to discuss this abstraction directly would be a great advantage for the whole range of comparative analysis.

3.2. Principal Components Analysis

One goal of Principal Components Analysis (PCA) is the mathematical derivation of a "relatively small number of variables" from those actually measured [10]. Landau and Everitt describe PCA as "a method of data reduction that [simplifies] analysis of the data" [8]. Accordingly, the output of PCA (the principal components) are combinations of the original variables in such a way as to account for as much variation in the original data as possible.

Two conditions must be met if PCA is to be used appropriately: 1) a relationship (correlation) must exist among the original variables and 2) the sample size must be relatively large in relation to the number of original variables [8, 10]. The statistical software searches through the tested data to find a new variable (a *component*) that accounts for as much variability as possible and assigns an *eigenvalue* to the component, effectively telling us how much of the variability is accounted for. After a first component is extracted and assigned an eigenvalue, PCA searches for additional components not correlated with the first, assigning values to each. There will be as many components as original variables and the cumulative percentage of variance explained always equals 100%.

Eigenvalues offer two important qualities. First, values over 1.0 indicate that a component explains more variance than any single original variable can [10]. Second, minor differences in values indicate similar abilities to account for variation in the data.

3.3. PCA of lenition data

Using SPSS software, PCA was run on the data with the four input variables (total duration, intensity, periodicity, and burst absence) that indicate weakening, as discussed in section 2.

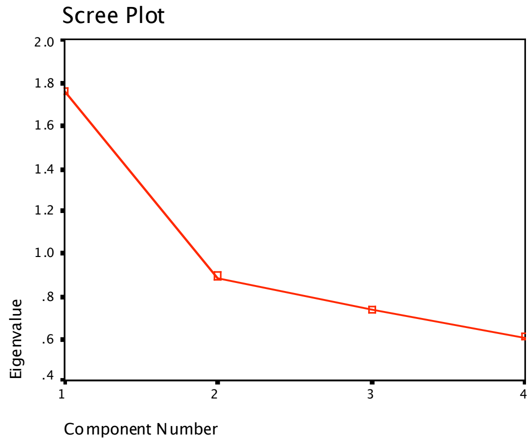
PCA returns one component with an eigenvalue over 1 (1.763) that accounts for 44% of the variance in the data (Table 2). While this number may not seem high, it is approximately twice the amount of variance explained by the next component, and its eigenvalue indicates that more variance is explained by this single component than by any individual measured variable.

Table 2: Total variance explained

	Initial Eigenvalues		
Component	Total	% of Variance	Cumulative %
1	1.763	44.083	44.083
2	.891	22.263	66.346
3	.739	18.479	84.824
4	.607	15.176	100.000

The Scree test [4] in Fig. 2 illustrates a decline in eigenvalue differences after Component 1. We therefore extract only the single component before the elbow in the plot, define it as a new variable, and rename it L (the lenition score).

Figure 2: Scree plot of components and eigenvalues



The component matrix in Table 3 shows how L is defined in terms of the original variables.

Table 3: Component score coefficient matrix for L

	L
Relative total duration	-.388
Intensity ratio	.439
Relative periodicity power	.331
Burst absence	.339

Table 3 shows that L is negatively loaded with the original variable of duration and positively loaded with intensity, periodicity, and burst absence. A negative loading of duration means that tokens with higher durations are lower in L scores, and the positive loadings mean that tokens with higher intensity, periodicity, and burst absence are higher in L scores. The loadings are generally in the same range, with duration and intensity loadings on the high side [10].

SPSS saves a standardized L weighting for each token based on the component loading in Table 3. L ranges from -2.79 to 2.55; higher scores indicate more weakening. The 28 unmeasurable tokens (weak approximants) were assigned L scores equal to the maximum L in the entire /p,t,k/ token set.

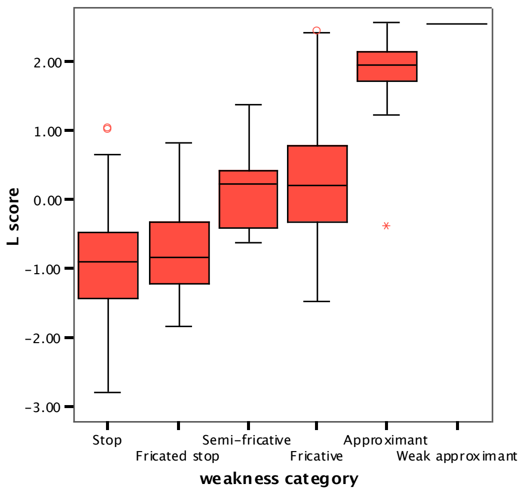
4. DISCUSSION

With L scores for each token in the dataset, we can compare the descriptives based on L scores to the allophonic analysis discussed in Section 2. Mean L scores for the six allophone categories are in Table 4. A boxplot of these means is in Fig. 3.

Table 4: Mean L scores by allophone

Allophone	N	Mean L score
Weak approximant	28	2.55
Approximant	28	1.85
Fricative	368	0.30
Semi-fricative	23	0.13
Fricated stop	80	-0.77
Stop	110	-0.94

Figure 3: Boxplot of L scores by allophone



A significant difference in L was found among the allophone categories, F (5, 631) = 168.588, $p < .001$. Games-Howell post hoc tests indicate no significant differences between the semi-fricative/fricative pairs or between the stop/fricated-stop pairs, a finding that is predicted by the relatively high loading of L with the original intensity variable. Recall from Section 2 that intensity values for allophone categories predict the following homogeneous subsets:

Figure 4: Homogeneous subsets predicted by L

WA	A	F SF	FS S

These findings easily justify , the use of this derived construct as a latent determiner of lenition. Not only can "L" be used in running descriptives and in testing the hypotheses central to the present study; it also represents a methodological step forward that can be applied to other problems in quantitative linguistic study.

5. REFERENCES

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