On the relationship between vowel length and locus equations: Comparing place of articulation discrimination using $F2_{onset}$ and $F2_{@burst}$

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Locus equations (LEs) represent the linear spectral relationship between the initial and the mid-point of the second formant in a CV sequence [Lindblöm, 1963; Sussman et al., 1991]. According to Sussman et al. [1991; 2012], LEs may constitute a source of relational invariance for the identification of stops' place of articulation and seem to be a good indicator of the degree of coarticulation in a CV sequence. As a matter of fact, it has been shown that LE coefficients (slope and y-intercept) may be broadly associated to place of articulation categories. In addition, when performing linear discriminant analysis (LDA) with either, slopes and y-intercepts, or $F2_{onset}$ and $F2_{mid}$ as predictors, good to perfect discrimination of stop place is achieved. LEs are also a reliable measure of the degree of coarticulation between a consonant and a vowel.A slope value close to 1 indicates a high degree of coarticulation while a lower slope indicates a lower degree of coarticulation.

In previous studies [Abuoudeh and Crouzet, 2014b,a] , we investigated the impact of vowel phonological length contrasts on both LE parameters and consonant classification for 5 voiceless consonants in Jordanian Arabic (JA) /t,tˤ,k,q,ʔ/ coarticulated with long vs. short vowels /iː,aː, uː, i,a,u/. Our analysis showed that the slope of consonants produced with long vowels are consistently lower than the slope of consonants produced with short vowels (see Table 1), this difference is significant ($F_{(1,2)} = 43.81, p < 0.05$) which is in line with the *degree of coarticulation hypothesis*, but this may have a deleterious impact on place of articulation categorization. We performed a series of LDA on a subset of our JA data (namely /t,k,q/ consonants only) to investigate whether vowel length would disturb consonant categorization as it does for LE slopes.

Results showed relatively low classification accuracy (see Table 2) using $F2_{mid}$ and $F2_{onset}$ as predictors. However, according to our analysis, timing parameters mainly had a negligible effect on consonant classification. Nevertheless, the predicted hypothesis may partly be hidden by the relatively low classification accuracies observed when compared with traditional studies. This issue may be related to $F2_{onset}$ position choice. In voiceless consonants there is a delay between the burst and the first laryngeal pulsations, therefore estimating frequency of the second vocal tract resonances at burst($F2_{@burst}$) would provide a better indicator of the consonant properties for place of articulation [Modarresi et al., 2005]. This could explain both the relatively high slope values of our data and the low classification rates. The aim of the present research is to compute LE and to perform LDA using $F2_{@burst}$ instead of $F2_{onset}$ in order to investigate this phenomenon more closely. To do so, we used linear techniques to predict the $F2_{@burst}$ frequency values (see Tables 3,4) and then replace $F2_{onset}$ by the resultant $F2_{@burst}$ values in all of the previous analysis. In the final paper we do an overall comparison between $F2_{onset}$ and $F2_{@burst}$ results, and investigate the implications of time factor in both cases.

	Slope		y-Intercept		R^2	
C	Short V	Long V	Short V	Long V	Short V	Long V
t	0.78	0.67	375	549	0.94	0.95
tˤ	0.77	0.54	198	384	0.95	0.86
k	0.96	0.94	-33	3	0.95	0.94
q	0.84	0.78	43	158	0.93	0.92
ʔ	0.93	0.83	-62	119	0.98	0.94

Table 1: Mean values of slopes, y-intercepts and R^2 of LEs for each consonant coarticulated with long and short vowels.

V./predictors	$F2_{onset} + F2_{mid}$
all	0.48
long	0.45
short	0.43

Table 2: Correct classification percentage for all consonants using $F2_{onset} + F2_{mid}$ as predictors with all vowels, long vowels and short vowels. These results are relatively low comparing with classical studies (70 % in [Sussman et al., 1991])

V. / C.	t	tˤ	k	q	ʔ
a	1523	1137	1645	1225	1427
u	1291	1120	990	961	1066
i	1957	1549	2077	1726	2057

Table 3: Mean values of $F2_{onset}$ for all consonant for each vocalic timber

V. / C.	t	tˤ	k	q	ʔ
a	1591	1108	1819	1185	1402
u	1640	1256	913	989	967
i	1939	1279	2210	1554	2088

Table 4: Mean values of $F2_{@burst}$ for all consonant for each vocalic timber

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