ACOUSTIC TESTING FOR PHONOLOGIZATION

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1. INTRODUCTION

Phonologization [1, 2] occurs when some variation in production occurs with frequency and is stabilized as a new pattern [1, 3]. The Optimality Theory grammar of a language is its constraint ranking. Phonologization occurs when categorical, non-numeric versions of numerically weighted phonetic constraints [4] enter the strict dominance relations of the grammar. This paper examines how this shift arises from the acoustic signal, focusing on gradience [5] in postvelar phenomena in Salish and Arabic.

2. PHONETIC TO PHONOLOGICAL OPTIMIZATION

Flemming [4] proposes that phonetic properties can be understood as the effect of the interaction of weighted constraints. He explains it as follows. In CV sequences, e.g., F_2 of the C and V are co-determined by a constraint against deviation from C and V F_2 targets and a constraint against quick articulator movement. Achieving both targets could mean quick speech, and slow movement could mean achieving neither target. The actual production is an optimization of this conflict. The constraint weighting is such that both targets are undershot. Degree of undershoot depends on exact weighting. In this model, the weightings figure into a mathematical cost function which determines the optimization, e.g.:

(1) Flemming's cost function for F2 in CV [4]

$$c = w_c(F2_C - F2_L)^2 + w_v(F2_V - F2_T)^2 + w_e(F2_C - F2_V)^2$$

where $F2_C$ is F_2 of the C, $F2_V$ is F_2 of the V, $F2_L$ is fixed target F_2 of the C, $F2_T$ is fixed target F_2 of the V, and w_c, w_v and w_e are positive weights.

The first two terms express 'Don't deviate from targets' separately for C and V. If the differences are minimal, cost on contrast will be minimal. The overall cost also includes cost on effort. This is that incurred by the difference between $F2_C$ and $F2_V$, as specified by the last term of the function, which expresses 'Don't move quickly'. If the difference is small, the articulators move quickly. As stated by Flemming, weighted constraints compute costs in real numbers. They reflect the scalar nature of phonetic factors and their additive effects.

This differs from the phonological grammar, as illustrated in (2). ALIGN-TR, with phonetic basis in $w_e(F2_C - F2_V)^2$, requires [TR], the phonological feature implemented as tongue root articulation, to be aligned with the word edges. IDENT, with phonetic basis in $w_c(F2_C - F2_L)^2 + w_v(F2_V - F2_T)^2$, requires that there be no feature change between input and output. In (2), the input is between slashes; competing outputs are between square brackets. Output candidate b is optimal because it best satisfies the two discrete constraints, given their ranking: it satisfies the higher ranked ALIGN-TR whereas candidate a violates it ('*'), fatally so ('!').

As phonetic properties are gradient but phonological properties are not, a key trigger for the shift between the phonetics and phonology is degree of gradience.

(2)

/t̲a/	ALIGN-TR	IDENT
a. [t̲a]	*!	
☞ b. [t̲a̲]		*

3. ACOUSTIC STUDY

3.1 Method and procedure

St'át'imcets Salish words were produced by an adult male native speaker, aged 68 years. Palestinian Arabic words were produced by an adult male native speaker, aged 45. See the Appendix. For St'át'imcets, 60 V tokens and 72 C tokens were analyzed. For Palestinian, 120 V tokens were analyzed. Recording used a Marantz P420 tape recorder. Digitization was at 22.05 kHz sampling rate. Analysis used *Multi-Speech 3700*. F_1 and F_2 of Vs and approximants were measured. The resonance in the area of F_2 was measured for fricatives, and stops (in the release burst). Measurements were at durational midpoint. Formant ('F') centre frequency was taken as the average of values obtained from wide and narrowband spectrograms using the values provided by *Multi-Speech 3700* with placement of the cursor on the estimated F centre.

3.2 Results: St'át'imcets Salish

Figs. 1-3 present data from St'át'imcets relevant to uvularization spread, lowering of [ə] before [ʔ], and lowering of labialized uvulars. F means (in Hz) and standard deviations (SDs) are shown. SD is used here to determine if a property is gradient, as phonetic properties vary more than phonological ones [5]. Fig. 1 shows that F_2 is dropped for [a] preceding and following a uvularized C ('C̲'). F_1 is raised in both cases. The effects are greater preceding. The SDs provide no evidence for identifying the greater F effects preceding the C̲ as phonological: F_2 SD in that case is even greater than F_2 SD for [a] following a C̲ (86 vs. 46). This counters usual assumption that the leftward coarticulation is phonological in this language. Fig. 2 shows that [ə] is lowered preceding [ʔ], as F_1 is raised in that context. The F_1 SD is lower preceding [ʔ] than preceding C (61 vs. 71). This indicates that the [ə] lowering, considered phonetic in this language, is perhaps becoming phonologized. For Fig. 3 we focus on F_2, the one resonance measurable for all C types. The labialized uvulars, including [x̲ʷ] ([χʷ]) and [k̲(')ʷ] ([q(')ʷ]), show a drop in 'F_2', as expected. F_2 SD is lower for [ʁ(')ʷ] than for [ʁ(')] (31 vs. 69), indicating that the lowered F_2 for [ʁ(')ʷ] phonological. The [ʁ(')ʷ] is produced with auditorily perceptible pharyngeal articulation, and is [ʕ(')ʷ]. The lower F_2 of pharyngeal compared to uvular articulation enhances the lower F_2 of the labialization. For [x̲ʷ] and [k̲(')ʷ] the variation in F_2 is greater than for their plain variants, indicating that their F_2 drop with labialization is phonetic. The [x̲ʷ] and [k̲(')ʷ] are not perceptibly pharyngeal, i.e., they are not [ħʷ] and [ʡ(')ʷ].

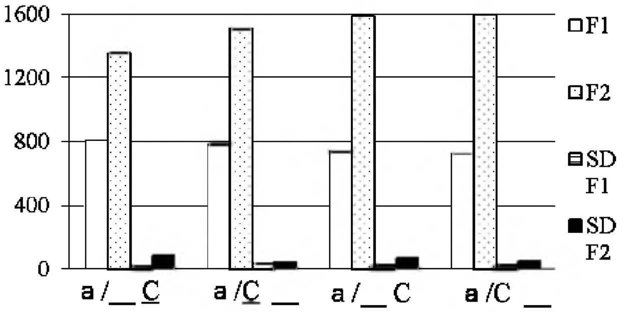

Fig. 1. F_1 and F_2 of St'át'imcets Vs in C-V/V-C sequences

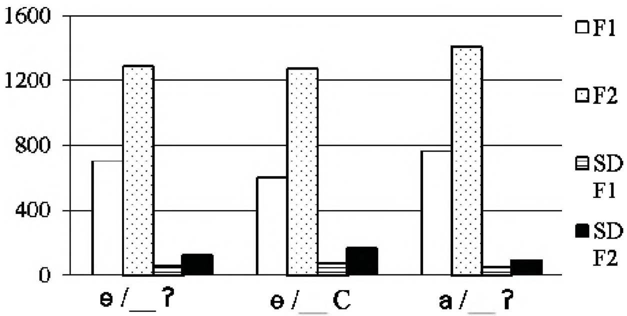

Fig. 2. F_1 and F_2 of St'át'imcets [ə] and [a] before [ʔ]

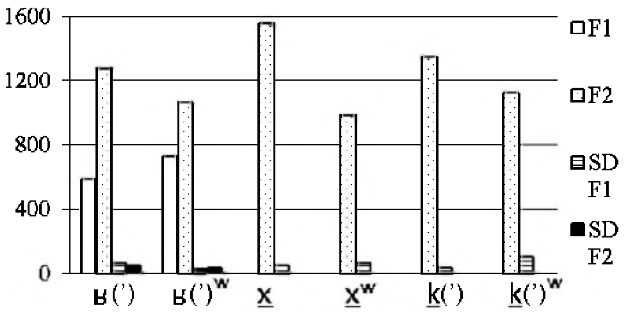

Fig. 3. Resonances of non-labialized and labialized St'át'imcets uvulars

3.3 Results: Palestinian Arabic

Fig.4 presents data from Palestinian relevant to uvularization of the low V ('A'), opacity to uvularization spread by the high front V ('I'), and lack of pharyngealization for a stem-final V, which was 'U' in the carrier word [6]. We take 40 as normal SD for Fs of a distinct sample [7]. SDs of 19.2 (F_1) and 29.8 (F_2) for uvularized A indicate that its coarticulation is phonological. SDs of 13.7 (F_1) and 31.7 (F_2) for I adjacent to C indicate phonological lack of coarticulation for that V. In this language, Vs in closed syllables are pharyngealized (i.e., become rtr) except when stem-final. SDs of 30.2 (F_1) and 52.7 (F_2) for closed-syllable, stem-final U indicate that that rtr quality for stem-final Vs is perhaps becoming phonologized.[1]

4. CONCLUSION

This work illustrates acoustic testing for phonologization. Gradience was examined and found to underlie phonologized patterns, and to indicate that certain patterns previously considered phonological are perhaps phonetic.

[1] Other SDs from the data are: 13.2 (F_1), 15.9 (F_2) for nonuvularized A; 8.4 (F_1), 27.8 (F_2) for I not adjacent to C; 9.1 (F_1), 17.8 (F_2) for closed syllable, non-stem-final U.

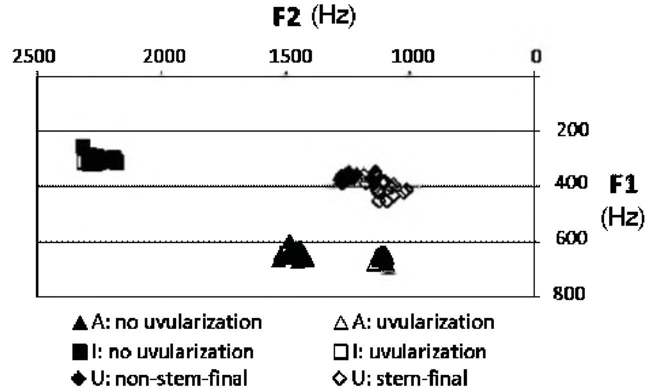

Fig. 4. F_1, F_2 plot of Palestinian Vs in postvelar contexts

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APPENDIX

For each word, the number of tokens recorded is given in parentheses.*

A. St'át'imcets words recorded for the acoustic study

a. ʔaχʷxal 'dig' (6) — b. xʷəʔaz 'no, not' (2)
c. maqaʔ 'snow' (6) — d. mɛχaɬ 'black bear' (6)
e. qəʔəz'ʔul 'tired out' (2) — f. qəʔamaj'ɬ 'breastfeed' (2)
g. məʔəʁ' 'dawn' (4) — h. pəʔəʁ' 'pale, faded' (2)
i. təwæn 'salmon berry' (2) — j. təqiw 'horse' (2)
k. zəhakaʔ 'right hand' (2) — l. zəwatən 'know' (2)
m. wənaxʷ t͡ɬ'uʔ 'true' (2) — n. χʷumqaʔ 'salmon head' (6)
o. q'ʷijʃqin 'axe' (2) — p. ts'uqʷaz' 'small fish' (6)
q. χʷaʔʃ 'sockeye' (6) — r. χaχtʃaʔ (name of Band) (6)
s. wəʁən 'sort s.t.' (2) — t. k'iʔiʁ'ʷ 'feel run down' (2)
u. ʁawən 'gather things' (2) — v. ɬəʁʷilx 'jump' (2)
w. kanɬiʁʷa 'swallow s.t. wrong' (2) — x. q'ʷəʁʷp 'slide down' (4)
y. q'ʷəʁʷpalwaʃ 'pants falling down' (4) — z. ləʁʷən 'hide' (2)
a'. məluχʷakaʔ 'sprain one's hand' (2) — b'. ziʔzəʁ t͡ɬ'uʔ 'always' (2)
c'. kanɬiʁʷkana 'I swallowed s.t. wrong' (2) — d'. ʁʷuj't 'sleep' (2)
e'. ʔəʔχaʔ 'sacred, supernatural talented' (2)

B. Palestinian words recorded for the acoustic study

a. kəsæːt 'cups' (20) — b. bəsːɑːt 'busses (20)
c. tiːn 'fig' (20) — d. tiːn 'mud' (20)
e. fulːə (type of doll) (20) — f. bɪsəkfu-lnæːʃ 'they don't clap for us' (20)

* IPA is used. Underlining denotes uvularization. The hyphen in B(f) indicates that the [u] in that word is at a right stem edge.