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Author(s): Stefan Benus, Adamantios Gafos, and Louis Goldstein

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# Phonetics and Phonology of Transparent Vowels in Hungarian

STEFAN BENUS[†], ADAMANTIOS GAFOS[‡], LOUIS GOLDSTEIN[¶]
[† ‡] *New York University*, [‡ ¶] *Haskins Laboratories*, [¶] *YaleUniversity*

## 1. Introduction

Vowel harmony is a requirement by which vowels in a certain domain agree in one or more phonetic features.[1] In Hungarian, the feature subject to harmony is the horizontal position of the tongue ([±back]). In many Hungarian roots, vowels in a word are either all front or all back, as in *öröm* 'joy', *város* 'city' (umlaut denotes front round vowels, and acute accent denotes length). In such roots, the backness of the suffix vowel is determined by the backness of the root vowels, e.g. *öröm-nek* 'joy'(dative), *város-nak* 'city'(dative).

In the so-called disharmonic roots, front vowels can combine with back vowels. In these roots, the quality of the root-final vowel determines the quality of the suffix vowel as in *parfüm-nek* 'perfume'(dative), *nüansz-nak* 'nuance'(dative). Vowels such as /ü/, /a/ are called opaque, because they block agreement between the initial and the suffix vowels. Certain vowels, however, do not block such agreement: *papír-nak* 'paper'(dative), *kávé-nak* 'coffee'(dative). Vowels like */í/* and */é/* are called transparent (henceforth TV).

Despite the significant body of work on vowel harmony (Clements 1977, S. Anderson 1980, Kiparsky 1981, Hulst & Smith 1986, Archangeli & Pulleyblank 1994, Ohala 1994, Ní Chiosáin & Padgett 1997, Ringen & Vago 1998, Baković & Wilson 2000, Krämer 2001), surprisingly little attention has been devoted to the phonetics of TVs. In line with the current research program on the role of phonetics in phonology (e.g. Steriade 1997), we believe that in order to understand the nature of transparency, both phonetic and phonological data should be studied. In this paper, we report preliminary results from such a study. At a broad level, we argue that phonetic details play a crucial role in determining the nature of transparency as well as the phonological pattern of suffix selection.

## 2. Transparent vowels

The Hungarian TVs consist of the front unround vowels {i [i], í [i:], é [e:], e [ɛ]}. In monosyllabic roots, TVs usually select front suffixes, as shown in (1). This is

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expected since TVs are front. However, there is a limited set of about sixty mostly monosyllabic roots where {í, i, é} select back suffixes, as in (2) (Vago 1980).

| | | | | |
|---|---|---|---|---|
| (1) | cím-nek/*nak | 'address'(dative) | szél-nek/*nak | 'wind'(dative) |
| | hisz-nek/*nak | 'believe'(3rd p. pl.) | szem-nek/*nak | 'eye' (dative) |
| (2) | híd-nak/*nek | 'bridge'(dative) | cél-nak/*nek | 'aim'(dative) |
| | nyit-nak/*nek | 'open'(3rd p. pl.) | | |

Not all TVs are equal, however. In polysyllabic roots, a systematic difference between {i, í, é} vs. /e/ emerges. If a back vowel (denoted with A) is followed by one of the three TVs {i, í, é}, the suffix vowel must be back, as shown in (3). If a back vowel is followed by /e/, suffix vowels vacillate between the front and back version, as shown in (4). Vacillation in suffix selection results also when the back vowel is followed by two TVs, as shown in (5). Finally, as in (6), when the second of the two TVs is /e/, the suffix vowel must be front.

| | | | |
|---|---|---|---|
| (3) | A + {i, í, é} | papír-ban/*ben | 'paper'(inessive) |
| | back suffix | buli-ban/*ben | 'party'(inessive) |
| | | kávé-ban/*ben | 'coffee'(inessive) |
| (4) | A + /e/ | hotel-ban/ben | 'hotel'(inessive) |
| | vacillation | Ágnes-ban/ben | 'Agnes'(inessive) |
| (5) | A+TV+TV | aszpirin-ban/ben | 'aspirin'(inessive) |
| | vacillation | oxigén-ban/ben | 'oxygen'(inessive) |
| (6) | A+TV+/e/ | kabinet-*ban/ben | 'administration'(inessive) |
| | front suffix | november-*ban/ben | 'november'(inessive) |

Clearly, transparency is not a binary quality of vowels. Rather, the vowels {i, í, é, e} display a continuum of phonological behavior with full transparency and full opacity at the two extremes (compare 3, 6). Both the number and the quality of the TVs are factors affecting suffix selection (see also Farkas and Beddor 1987, Ringen and Kontra 1989).

## 3. Articulatory experiment

In the experiment, we tested the well-accepted assumption in phonology that TVs do not participate in vowel harmony (at least on the surface). We wanted to find out if the TVs are produced differently depending on their harmonic context ([a-i-a] vs. [e-i-e]). If there is no difference, the phonological assumption above would be supported also phonetically. If there is a difference, we wanted to find out if this difference is phonologically significant or the result of coarticulation.

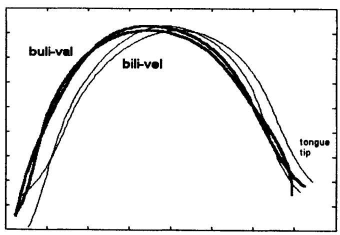
Four Hungarian subjects read a randomized list of stimuli words embedded in the frame sentence. Stimuli words contained TVs in front/back contexts with matched consonantal environment. A sample is given in (7).

(7)

| **Back** | **Front** | **Suffix** |
|---|---|---|
| kábít-om [ka:bi:tom] 'daze' | répít-em [re:pitɛm] 'send' | 1st p. sg. poss. |
| buli-val [bulival] 'party' | bili-vel [bilivɛl] 'pot' | Instrumental |
| bódé-tól [bo:de:to:l] 'hut' | bidé-től [bide:tø:l] 'bidet' | Ablative |
| hárem-ba [ha:rɛmbɔ]'harem' | érem-be [e:rɛmbɛ] 'medal' | Illative |

We assumed that the participation of the TVs in palatal vowel harmony is directly related to the degree of horizontal tongue body retraction. Since all TVs are front, the target of the tongue body movement for a TV was assumed to be its extreme front position. To observe this movement, we first employed Ultrasound (Stone 1997). We traced the tongue surface at the target location of the TV.[2] Then we compared the obtained surface shapes from the same TV in a front and in a back context. We found that TVs are generally more retracted in the back harmony context. This is illustrated in (8).

(8) Retraction of /i/ in back vs. front harmony (*buli-val* vs. *bili-vel*)




In order to quantify the differences observed in Ultrasound, we employed Emma (Perkell et al. 1992). Emma offers highly precise kinematic data about the movement of a limited number of points (receivers) on the tongue. As with the Ultrasound data, we measured the most frontward position of the receiver on the tongue body during the TV. Then we calculated the difference in tongue body retraction between the front and back environments.

We report the results from one subject. Analysis of the other subjects is currently in progress. It was found that the horizontal position of the tongue body receiver differs as a function of the harmonic context: the TVs are more retracted in the back context than in the front context. The average difference between front and back contexts is 0.67mm. Pooling across vowels, the tongue body receiver locations show a significant difference (paired t-test, $p = 0.006$, $N = 232$ pairs). Per-vowel differences were /í/ 0.51; /i/ 0.06; /é/ 1.43; /e/ 0.72 mm.

Can the observed differences in tongue dorsum retraction be due to coarticulation from the adjacent vowels? To address this question, retraction effects must be compared between a vowel harmony context and a context where only coarticulation is in effect. In our stimuli set, we had two such comparisons.

[2] In our extractions, we employed a method developed by Khalil Iskarous at Haskins Laboratories.

First, note that vowel harmony in Hungarian is blocked across the boundary between two words, two parts of a compound, and between a verb and a prefix. A TV flanked by a harmony-blocking boundary from both sides may be retracted only due to coarticulation, see (9b). A TV in a harmony context, however, may be retracted due to coarticulation, harmony, or both, see (9a). Thus, a difference in retraction between TVs in (9a) and (9b) would demonstrate that the observed retraction in the back harmony context could not be due to coarticulation only.

| | | |
|---|---|---|
| (9) | a. **Harmony** | b. **Coarticulation** |
| | kabin-ból 'cubicle'(ellat.) | Jós[ka mit mon]d? 'What is J. saying?' |
| | kópé-ban 'prankster'(iness.) | Fic[kó B[be:] ban]da 'Group of Ficko B.' |

Second, in some monosyllabic roots TVs select back suffixes, as in (10a), whereas in most such roots they select front suffixes, as in (10b). We compared TVs in these roots, as they appear in isolation (no overt inflectional markers). If any difference in tongue body retraction of the TVs between these two classes of roots is found, then it cannot be ascribed to coarticulation.

| | | |
|---|---|---|
| (10) | a. **Roots selecting back suffixes** | b. **Roots selecting front suffixes** |
| | síp 'whistle'(nom.) | cím 'address'(nom.) |
| | cél 'aim'(nom.) | szél 'wind'(nom.) |

The results from these two conditions are not conclusive. We had 22 tokens of the data exemplified in (9) but did not find any significant difference. Therefore, the observed difference in the tongue body retraction between front and back harmony might be due to coarticulation only. However, prosodic differences between the forms in (9a) and (9b) make this a non-trivial comparison. For example, in the realization of the tokens by our subject, the syllable containing the TV was always unstressed in the harmony condition, but consistently received phrasal stress in the coarticulation condition.

Our stimuli included twelve pairs of the stems shown in (10). Data show a tendency for the TVs selecting back suffixes to be more retracted than the vowels selecting front suffixes. For example, tongue dorsum location differences between the two /í/s in the pair *síp-cím* were 1.77 and 1.19mm. This relationship obtains in nine out of twelve pairs. Unfortunately, the total number of pairs was small, which prevented statistical analysis. Despite this, the result from the monosyllabic roots suggests that the difference in tongue body retraction between front and back harmony context cannot be attributed to coarticulation.

To summarize the experiment, TVs are more retracted in the back harmony than in the front harmony context. This means that minute phonetic differences in tongue body position correlate with a full-fledged phonological alternation in suffixes. The data from bare roots suggest that this correlation cannot be explained by coarticulation only. Further experiments are necessary to obtain more robust results.

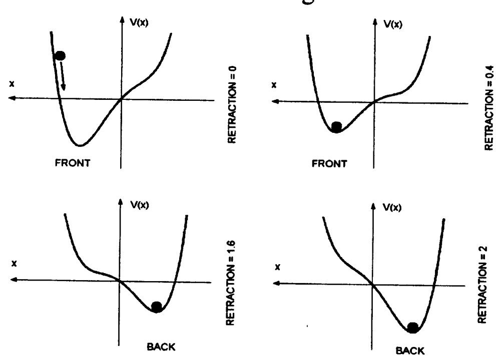
## 4. A dynamical model of suffix selection

How can small differences in details of articulation observed in section 3 be related to a categorical alternation in suffixes? Formally, the relation obtained between degree of retraction in the TV and suffix selection is nonlinear. Small changes in degree of retraction are associated with large (nonlinear) changes in suffix form. In this section, we propose a way to express this relation using the formal language of nonlinear dynamics (see Browman and Goldstein 1995 and Gafos, to appear, for background notions and motivation).

In the proposed dynamical model, the two discrete forms of an alternating suffix (e.g. dative *-nak* vs. *-nek*) are mapped to attractors of a dynamical system. We require that the choice of the attractor must be modulated by variation in R, representing the retraction degree of the root-final vowel. Mathematically, these ideas can be stated in the form of equation $dx/dt = N(x, R) + F(t)$. This equation expresses the temporal evolution of the suffix vowel (tongue body) constriction location variable, denoted by x, as a nonlinear function N of the current state x and the control parameter of retraction degree R. Given our requirements, a good candidate for N is the 'tilted' anharmonic oscillator, whose dynamics are described by $N(x, R) = (R-1) + x - x^3$. The factor $F(t)$ represents the presence of noise and can be ignored for now.

The asymptotic behavior of x in this equation can be visualized by looking at (11). The abscissa denotes values of tongue body constriction location for vowels. Negative x values represent front vowels; that is, as x increases, the constriction location moves toward more retracted (back) locations in the vocal tract.

(11) Suffix form as a function of retraction degree



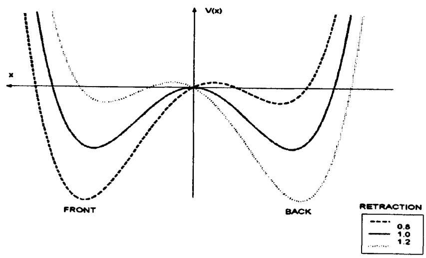

The value of constriction location for a suffix vowel can be interpreted by the position of a ball running downhill within the potential landscape $V(x) = (1-R)x - (1/2)x^2 + (1/4)x^4$, which can be obtained by integrating $N(x, R)$. The minima in the valleys of V(x) represent the stable fixed points of constriction location. These are the attractors, the preferred regions within the continuum of constriction location where the ball ends up. Starting with a retraction degree of $R = 0$, the potential V(x) is shown at the left side of the top panel in (11). There is one attractor, FRONT, corresponding to the front variant of the suffix. A ball left in this potential will end up in that attractor, and the suffix surfaces as front. Small increases in R result in smooth changes in the potential V(x), as shown in the top, right where R = 0.4. There is still only one attractor or one possible stable form for the suffix. The graphs in the lower panel show how the potential changes after a significant increase in R, R = 1.6 left, R = 2 right (intermediate R values to be discussed). A qualitative change is evident in the shape of V(x). The FRONT attractor has been replaced by a BACK attractor that is located at the other end of the constriction location axis and corresponds to the back variant of the suffix.

To illustrate how this model captures the essential properties of the data, consider a root with a TV, e.g. *papír-nak* 'paper'(dative). Vowel gestures in consecutive syllables are overlapped (Öhman 1966). We assume that the constraint driving palatal harmony requires that the back vowel /a/ and the front vowel /í/ minimize their differences in (horizontal) tongue body constriction location. Consequently, /í/ must be retracted when following a back root vowel and this is what we observed experimentally. Let us set /í/'s retraction degree (when it follows a back vowel) to some relatively high value of retraction, say $R_í$ = 1.6 or higher. According to the dynamical model of the suffix alternation, this value of retraction induces the back variant of the suffix, as shown in the bottom panel of (11). In this model, then, a categorical alternation in suffix form is brought by a scalar increase in the continuous variable of retraction degree R in the preceding root vowel. This corresponds to the standard view of harmony as agreement between root vowels and the suffix. A crucial difference, however, is that in this model small, non-contrastive differences in retraction R can result in categorical suffix alternations (the property of nonlinearity).

Next consider the case of an opaque vowel, e.g. *parfüm-nek* 'perfume' (dative). The suffix vowel here surfaces as front. What makes /ü/ different from /í/ in this respect? We view transparency as grounded in the quantal nature of the relation between articulation and sound (Gafos 1999). On the one hand, Stevens (1989) and Wood (1979) have shown that the acoustic outputs for non-low front vowels are insensitive to a limited amount of variation in the horizontal position of the tongue body. Therefore, /í/ may be retracted to some degree $R_í$ without losing perceptual identity. On the other hand, Wood (1986) has shown that the front round vowels are less stable than their unround counterparts in that their acoustic output is very sensitive to even small amounts of articulatory variation in the horizontal position of the tongue. Consequently, if /ü/ were to be retracted to a degree comparable to $R_í$ it would lose its perceptual identity. Going back to our dynamical model in (11), then, if /ü/'s retraction degrees are limited to relatively small values ($R_ü < 0.4$), the attractor is FRONT and the suffix takes its front variant.

So far we have described the effects of varying retraction degree for relatively small and relatively large retraction values, as shown in (11). The result is a qualitative change from a front to a back attractor. In nonlinear dynamics, a change from one macroscopic state of the system to another implies an intermediate stage of fluctuation. This turns out to capture another essential aspect of the data, namely, vacillation. In (12), the potential V(x) is shown for three representative, intermediate values of R, 0.8, 1.0, 1.2. For each of these, there are now two minima representing the presence of two stable states, FRONT and BACK.

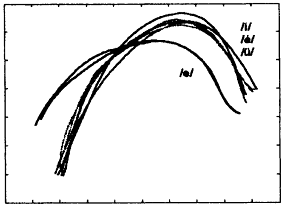
(12) Bistability for intermediate values of retraction




To see how bistability in an attractor landscape implies vacillation, we must turn to the effects of noise. In any model of a natural phenomenon, noise is introduced by the various low-level microscopic systems implementing the essential variables under modeling (here, the neuronal and myodynamic systems implementing tongue body constriction location). Mathematically, noise enters the model equation as a small, random fluctuation force F(t). This force pushes the position of the ball back and forth randomly. Consider, for example, a ball at position (0,0) in the bistable potential corresponding to $R = 1$ (solid line in 12). Due to the random kicks introduced by fluctuations, the ball will end up either at the left or the right side, and the suffix varies between a front and a back version.

There are two areas of vacillation in the Hungarian data. The first is vacillation induced by the low vowel /e/ as described in (4), e.g. *hotel-ban/ben* 'hotel'(inessive). The vowel /e/ then appears to be less transparent than {i, í, é}. Consistent with the Hungarian facts, in a cross-linguistic study of transparency, L. Anderson (1980) observes an implicational generalization related to vowel height: if /e/ is transparent, /i/ must be also but not vice versa. We have proposed that the transparency of {i, í, é} is grounded in their quantal properties, and specifically in the perceptual insensitivity of these vowels to articulatory perturbations in tongue body constriction location. Crucially, this is a property of the non-low front vowels (Stevens 1989, Wood 1979). Our ultrasound imaging showed that /e/ is different in a relevant sense from the other three TVs {i, í, é}. As shown in (13), /e/ is notably lower and more retracted compared to the vowels {i, í, é}, among which only minimal differences in height and backness can be observed (vowels were extracted from identical contexts). Because /e/ is less stable than {i, í, é}, it follows that /e/ can be retracted less than /í/, $R_e < R_{í}$. We may assume then that $R_e$ falls within the range of intermediate values shown in (12). For such values, the dynamics of suffix selection has two attractors, and the suffix form will show variation due to random fluctuations.

(13) Tongue shapes of /e/ [ɛ], /í/ [i:], /é/ [e:], /ü/ [y] (two tokens per vowel)



We now turn to the other area of vacillation, concerning multiple TVs as described earlier in (5). The generalization is that the more TVs between the back root vowel and the suffix vowel, the more likely it is that the suffix is front. To see how this vacillation can emerge from our model, consider a root with two TVs, e.g. *aszpirin* 'aspirin'. The crucial idea is that the degree of retraction on TVs should diminish with the distance between the initial back vowel of the stem and the TV. The farther the TV from the initial back vowel triggering harmony, the less retracted it will be. Thus, the first TV in *aszpirin* is predicted to be significantly retracted by some degree $R_1$ due to the harmony requirement, dictating minimization of the articulatory distance in constriction location between it and the first back vowel. The second TV in *aszpirin* is also predicted to be retracted because it is required to agree in constriction location with its preceding vowel. Clearly, however, less retraction $R_2$ is predicted on the second TV as its preceding TV is more advanced than a prototypical back vowel. If $R_2$ falls within the intermediate range of values generating a bistable potential, the macroscopic result is variation in the form of the suffix, *aszpirin-ban/ben*. We plan to test the empirically predicted values of retraction in a future study.

To summarize, we have proposed that vowel harmony is driven by articulatory agreement between overlapping vowel gestures, and that this agreement is constrained perceptually. Vowels differ with respect to their potential for agreement: /í/ is most retractable, /e/ is somewhat retractable, and /ü/ is minimally retractable. Articulatory-perceptual quantal relations are crucial in determining the degree to which a vowel can be retracted without losing its perceptual identity. Finally, we relate the continuous scale of retraction degree to the discrete suffix alternation using nonlinear dynamics, a formal language where continuity and discreteness coexist and interact within a unified framework.

## 5. OT formalism

In the previous section, we described vowel harmony as a phenomenon where articulatory agreement among vowels is constrained by perceptual considerations. In this section, we use Optimality Theory (Prince and Smolensky 1993) to show how the conflict between the pressures for articulatory agreement and perceptual faithfulness is resolved with constraint ranking. The crucial proposal is that faithfulness between the input and output forms is evaluated separately for perceptual and articulatory domains. This is motivated by the quantal relationship between articulation and perception (Stevens 1989, Wood 1979).

We propose three basic constraints. Harmony is construed as an articulatory process mandated by the AGREE constraints in (14). AGREE(TBCL)$_{Rt}$ requires that consecutive vowels have identical values of tongue body constriction location. Thus, with respect to this constraint, 'a-[i]' is less harmonic than 'a-[ɯ]'. AGREE(TBCL)$_{Rt\text{-}Suff}$ requires that the backness of the suffix vowel depend on the retraction degree of the root-final vowel (section 4). This constraint is violated if, for example, the retraction degree is R = 2, but the suffix is front (see 11). In conflict with the AGREE constraints are the faithfulness constraints in (15), (16). The first mandates perceptual and the second articulatory constancy.

(14) AGREE(TBCL)$_{Rt}$ – Consecutive root vowels minimize their difference (distance) in terms of TBCL (Tongue Body Constriction Location).
AGREE(TBCL)$_{Rt\text{-}Suff}$ – The TBCL value of the suffix vowel is determined by the retraction degree R of the preceding root vowel.

(15) IDENT$_{Perc}$(FRONT) – Corresponding vowel gestures in the input and output are perceived as front.

(16) IDENT$_{Art}$(TBCL) – Corresponding vowel gestures in the input and output have identical specifications for TBCL.

Tableau in (17) shows how transparency is formalized in OT. The input is a bisyllabic root where a back vowel is followed by one of the TVs {i, í, é}, e.g. *papír*. The candidates show the perceptual output on the top in '[ ]' and the articulatory output on the bottom in '{ }'. The degree of retraction is given by the value of R and illustrated with arrows, where two arrows mean more retraction than a single one.

(17) Transparency; TVs maximize articulatory agreement with the initial vowel without compromising perceptual identity

| (a-i)$_{Rt}$(nVk)$_{Suff.}$ (pa-pír)$_{Rt}$-(nAk)$_{Suff.}$ | IDENT$_{Perc}$ (FRONT) | AGREE (TBCL)$_{Rt}$ | AGREE (TBCL)$_{Rt\text{-}Suff.}$ | IDENT$_{Art}$ (TBCL) |
|---|---|---|---|---|
| a. a - [i] – e {i} R = 0 | | **! | | |
| b. a - [ɯ] – a {⇉i} R = 2 | *! | | | ** |
| c. a - [i] – e {→i} R = 1.6 | | * | *! | * |
| d. a - [i] – a ☞ {→i} R = 1.6 | | * | | * |

Candidate (17a) is faithful to the input both articulatorily and perceptually. Due to the significant articulatory distance between the non-retracted TV and the initial vowel, AGREE(TBCL)$_{Rt}$ is violated twice (compare with (17d) where the TV is retracted, decreasing the articulatory distance from the initial vowel). To avoid violating AGREE(TBCL)$_{Rt}$, the /i/ in (17b) is significantly retracted to {⇉i}, exemplified with R = 2. This, however, results in a vowel that is perceptually not front, violating IDENT$_{Perc}$(FRONT). The /i/ in candidates (17c,d) is retracted less than (17b), {→i}, R = 1.6, and each candidate incurs one violation of IDENT$_{Art}$(TBCL). Due to this retraction, the articulatory agreement with the initial root vowel is better than in (17a) but worse than in (17b). Hence, both (17c) and (17d) receive one violation of AGREE(TBCL)$_{Rt}$. Moreover, this retraction of /i/ does not change its perceptual identity and (17c,d) do not violate IDENT$_{Perc}$(FRONT). Based on (11), the dynamical system selects a back suffix if R = 1.6. Candidate (17c), however, selects a front suffix in violation of AGREE(TBCL)$_{Rt\text{-}Suff}$. Given that (17d) is the output, the ranking is IDENT$_{Perc}$(FRONT) >> AGREE >> IDENT$_{Art}$(TBCL). AGREE must dominate IDENT$_{Art}$(TBCL) since the opposite ranking would favor (17a) over (17d). Similarly, IDENT$_{Perc}$(FRONT) must dominate AGREE since the opposite ranking would favor (17b) over (17d). The two AGREE constraints are not ranked, since they are never in conflict; they refer to different domains. Intuitively, tableau (17) expresses the idea that TVs can maximize articulatory agreement with the initial back vowel while preserving their perceptual identity.

Tableau (18) shows the OT formalism of opacity. In the input, a back vowel is followed by a front rounded vowel. The intended /ü/ in candidates (18a,b) is retracted in order to avoid multiple AGREE violations. Since any retraction of front rounded vowels significantly affects perception (Wood 1986), both candidates violate top-ranked IDENT$_{Perc}$(FRONT). Note that the degree of retraction (R = 1.6) allowed for /i/ is not allowed for /ü/. Candidates (18c,d) show no or minimal retraction (R = 0.4), hence the double violation of AGREE(TBCL)$_{Rt}$. Candidate (18c), however, also violates AGREE(TBCL)$_{Rt\text{-}Suff}$. This is because, when retraction is minimal, our dynamical model in (11) dictates the front version of the suffix.

(18) Opacity; perceptual constancy prevents significant articulatory retraction

| (a-ü)$_{Rt}$-(V{a,e})$_{Suff.}$ (parfüm)$_{Rt}$(nVk)$_{Suff.}$ | IDENT$_{Perc}$ (FRONT) | AGREE (TBCL)$_{Rt}$ | AGREE (TBCL)$_{Rt\text{-}Suff.}$ | IDENT$_{Art}$ (TBCL) |
|---|---|---|---|---|
| a. a - [ʉ] – e {→y} R = 1.6 | *! | | | |
| b. a - [u] – a {⇉y} R = 2 | *! | | | |
| c. a - [y] – a {y} R = 0.4 | | ** | *! | |
| d. a - [y] – e ☞ {y} R = 0.4 | | ** | | |

Recall from (2) that TVs in some monosyllabic roots select back suffixes, e.g. *híd-nak* 'bridge'(dative). This pattern is formalized in a way similar to (17). The

TVs in these roots are lexically-specified for some degree of retraction sufficient to induce a back vowel according to the model in (11), R > 1.6. Output *híd-nak* satisfies AGREE(TBCL)$_{\text{Rt-Suff}}$ and since it reproduces the lexically specified articulatory retraction, while still perceived as front, it is selected as the winner.

Finally, the phonological pattern of vacillation follows from the determined ranking too. Both output forms, *hotel-nak* and *hotel-nek* 'hotel' (dative), have a retracted vowel /e/. Due to the quantal nature of /e/, more retraction would violate IDENT$_{\text{Perc}}$(FRONT) whereas no retraction would cause a fatal violation of AGREE(TBCL)$_{\text{Rt}}$. Given the model described in (12) and the intermediate degree of retraction $R_e \cong 1$, both *hotel-nak* and *hotel-nek* would fare equally on AGREE (TBCL)$_{\text{Rt-Suff}}$. Since they are tied on all constraints, they are both possible outputs.

## 6. Conclusion

We argued that the phonological pattern of suffix selection in Hungarian palatal vowel harmony must include reference to non-contrastive phonetic distinctions in the degree of tongue body backness of the transparent vowels. We sketched a theoretical model that allows us to relate these continuous phonetic distinctions to the discrete phonemic alternation using the mathematics of nonlinear dynamics.

## References


Anderson, Lloyd. 1980. Using asymmetrical and gradient data in the study of vowel harmony. In R. Vago (ed.) *Issues in Vowel Harmony*, 1-48. Amsterdam: John Benjamins.

Anderson, Stephen. 1980. Problems and perspectives in the description of vowel harmony. In R. Vago (ed.) *Issues in Vowel Harmony*, 271-340. Amsterdam: John Benjamins.

Archangeli, Diana and Douglas Pulleyblank. 1994. *Grounded Phonology*. Cambrdige, MA: MIT Press.

Baković, Eric and Colin Wilson. 2000. Transparency, strict locality and targeted constraints. In R. Billerey & D. Lillehaugen (eds.) *WCCFL 19 Proceedings*, 43-56. Somerville, MA: Cascadilla Press.

Browman, Catherine and Louis Goldstein. 1995. Dynamics and articulatory phonology. In T. van Gelder & B. Port (eds.) *Mind as Motion*, 175-193. Cambridge, MA: MIT Press.

Clements, George. 1977. Neutral vowels in Hungarian vowel harmony: An autosegmental interpretation. In J. Kegl, D. Nash, & A. Zaenen (eds.) *Proceedings of NELS 7*, 49-64.

Farkas, Donka and Patrice Beddor. 1987. Private and equipollent backness in Hungarian. In A. Bosch, B. Need & E. Schiller (eds.) *Papers from the Twenty-Third Annual Regional Meeting of the Chicago Linguistic Society* (CLS 23), Part II, 90-105. Chicago, IL: Chicago Linguistic Society.

Gafos, Adamantios. 1999. *The Articulatory Basis of Locality in Phonology*. New York: Garland.

Gafos, Adamantios. To appear. Dynamics in grammar: Comment on Ladd and Ernestus & Baayen. In L. Goldstein, D. Whalen, C. Best & S. Anderson (eds.) *Varieties of Phonological Competence (Laboratory Phonology 8)*. Mouton de Gruyter.

Hulst, Harry van der and Norval Smith. 1986. On neutral vowels. In K. Bogers, H. v.d. Hulst, & M. Mous (eds.) *The Phonological Representation of Suprasegmentals*, 233-279. Dordrecht: Forris.

Kiparsky, Paul. 1981. Vowel harmony. Ms., MIT.

Krämer, Martin. 2001. Vowel harmony and correspondence theory. PhD dissertation, Heinrich-Heine-Universität, Düsseldorf.

Ní Chiosáin, Maire and Jay Padgett. 1997. Markedness, segment realization, and locality of spreading. Report LRC-97-01, Linguistic Research Center, University of California, Santa Cruz. [ROA-188].

Ohala, John. 1994. Towards a universal, phonetically-based, theory of vowel harmony. *Proceedings of International Conference on Spoken Language Processing*, 491-494.

Öhman, Sven. 1966. Coarticulation in VCV utterances: Spectrographic measurements. *JASA* 39, 151-168.

Perkell, Joseph, Marc Cohen, Mario Svirsky, Melanie Matthies, Iñaki Garabieta & Michel Jackson. 1992. Electromagnetic midsagittal articulometer (EMMA) systems for transducing speech articulatory movements. *JASA* 92, 3078-3096.

Prince, Alan and Paul Smolensky. 1993. Optimality theory: Constraint interaction in generative grammar. Ms., Rutgers University and University of Colorado.

Ringen, Catherine and Miklós Kontra. 1989. Hungarian neutral vowels. *Lingua* 78, 181-191.

Ringen, Catherine and Robert Vago. (1998). Hungarian vowel harmony in Optimality Theory. *Phonology* 15, 393-416.

Steriade, Donca. 1997. Phonetics and phonology: The case of laryngeal neutralization. Ms., UCLA.

Stevens, Kenneth. 1989. On the quantal nature of speech. *Journal of Phonetics* 17, 3-45.

Stone, Maureen. 1997. Laboratory techniques for investigating speech articulation. In J. Hardcastle & J. Laver (eds.) *The Handbook of Phonetic Sciences*, 11-32. Oxford: Blackwell Publishers.

Vago, Robert. 1980. *The Sound Pattern of Hungarian*. Washington: Georgetown University Press.

Wood, Sidney. 1979. A radiographic analysis of constriction location for vowels. *Journal of Phonetics* 7, 25-43.

Wood, Sidney. 1986. The acoustic significance of tongue, lip, and larynx maneuvers in rounded palatal vowels. *JASA* 80, 391-401.

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Stefan Benus
NYU, Linguistics Dept.
719 Broadway, 4th fl.
New York, NY 10003

sb513@nyu.edu

Adamantios Gafos
NYU, Linguistics Dept.
719 Broadway, 4th fl.
New York, NY 10003

adamantios.gafos@nyu.edu

Louis Goldstein
Haskins Laboratories
270 Crown St.
New Haven, CT 06511

goldstein@haskins.yale.edu