Variability and Trigger Competition in Finnish Disharmonic Loanwords

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1. Introduction

In languages with vowel harmony processes, a segment which fails to undergo harmony may be either *transparent* (skipped by harmony) or *opaque* (blocking further propagation of harmony). Furthermore, in languages with multiple non-undergoers, some segments may be treated as transparent while others are opaque. In Hungarian, for example, Hayes & Londe (2006); Hayes et al. (2009) found that non-undergoing [i] was nearly always transparent, while [e] exhibited clearly variable behavior, and [ɛ] was most often opaque. In Finnish, Ringen & Heinämäki (1999) found that, among vowels which may be optionally transparent in disharmonic loanwords, higher vowels were more likely to be treated as transparent than their lower counterparts.

Several explanations have been proposed to account for the kind of transparency/opacity asymmetries seen in Hungarian and Finnish. Kaun (1995); Nevins (2004) argue that higher vowels are more likely to be transparent because they are less sonorous, and therefore constitute less of an interruption to the harmony domain. Benus (2005); Benus & Gafos (2007) claim that the quantal properties of vowels are responsible; high vowels can tolerate more coarticulation along the front/back dimension, and increased coarticulation results in a higher likelihood of passing along featural information to subsequent segments. Hayes et al. (2009); Kimper (2011) propose that higher vowels are more likely to be transparent because they are poor triggers for front/back harmony, and therefore less likely to initiate their own harmony domain for the opposing feature value.

In this paper, we present experimental evidence which supports the view that the choice between transparency and opacity is influenced by relative trigger strength. Finnish speakers were presented with novel disharmonic nonce words, and asked to choose between suffixed forms which exhibited either transparent or opaque harmony. Subjects were more likely to choose tranparency when the medial non-undergoer was high (consistent with the results in Ringen & Heinämäki 1999); furthermore, subjects were more likely to choose transparency when the initial trigger was low, matching the predictions of a model based on trigger strength but not the predictions of the alternative approaches.

The paper is organized as follows. Section 2 provides background on vowel harmony and variable transparency in Finnish, outlines the competing sources of explanation for the observed asymmetries, and highlights the predictions made by each approach. Sections 3 and 4 present the design and results of the experiment, and Section 5 compares those results to the predictions established in Section 2.

2. Harmony in Finnish Loanwords

Finnish exhibits a well-described system of harmony along the front-back dimension (Kiparsky, 1973, 1981; Goldsmith, 1985; Ringen, 1988; Steriade, 1987; Vago, 1988:and others). The inventory is as in (1) — low vowels and round vowels are paired along the front/back dimension, but front unrounded vowels are unpaired (they lack back counterparts [ɯ,ɤ]).

(1) **Finnish Vowel Inventory**

i	y		u
e	ø		o
æ		a	

Within native roots, paired front and back vowels may not co-occur. Furthermore, suffix vowels alternate to take on the feature specification of the root (2).

(2) **Finnish Back Harmony**

    a.   pøytæ-næ   'table-ESS'
    b.   pouta-na   'fine weather-ESS'

The unpaired front vowels [i,e] have often been described as neutral, since they may co-occur with both front and back vowels. When a neutral vowel intervenes between two paired vowels, it behaves as transparent — both root co-occurrence restrictions and suffix alternations continue to apply to the flanking paired vowels, regardless of the neutral intervenor. The suffix vowels in (3) all must agree with the non-neutral root vowels — for example, a back initial vowel in (3a) requires a back suffix, despite the intervening front [i].

(3) **Finnish Transparent [i,e]**

    a.   tunte-vat   'feel-3PL'
    b.   puhe-han   'speech-EMPH'
    c.   tsaari-na   'car-ESS'
    d.   ukit-han   'grandfathers-EMPH'
    e.   palttina-lla-ni-han   'with my linen cloth, as you know'
    f.   værttinæ-llæ-ni-hæn 'with my spinning wheel, as you know'
    g.   luo-da-kse-ni-ko   'for me to create?'
    h.   lyø-dæ-kse-ni-kø   'for me to hit?'

In the native vocabulary, neutral vowels are the only source of disharmony. However, loanwords are not forced to harmonize when they are adapted — as a result, front and back paired vowels can co-occur in borrowed roots (4). For example, in (4a), an initial back [u] is followed by a front [æ]; in (4b), an initial front [y] is followed by a back [a], and so forth.

(4) **Finnish Disharmonic Loanwords**

    a.   vulgæ:ri   'vulgar'
    b.   tyranni   'tyrant'
    c.   afæ:ri   'affair'
    d.   analy:si   'analysis'

While vowels in loanwords fail to undergo harmony, they still participate as triggers in harmonic suffix alternations (5). Loans where all stem vowels are back uniformly take back suffixes(5a–d), as do disharmonic stems consisting of a front–back sequence (5e–f). Loans consisting only of front vowels consistently take front suffixes (Ringen & Heinämäki, 1999).

(5) **Suffix Harmony with Loanwords**

    a.   tabasko-a   'Tabasco'   (*tabasko-æ)
    b.   jurtt-a   'yurt'   (*jurtt-æ)
    c.   rotunda-sta   'rotunda'   (*rotunda-stæ)
    d.   saluuna-sta   'saloon'   (*saluuna-stæ)
    e.   syntaksi-a   'syntax'   (*syntaksi-æ)
    f.   symptomi-a 'symptom' (*symptomi-æ)

In loanwords with back–front sequences, however, the value of the suffix vowel is variable; it may either be front or back (6). For example, the partitive singular suffix may surface as either back [-a] or

front [-æ] with a back–front word like [afæ:ri].[1] In other words, the non-neutral front vowels in these loanwords may either be transparent (surfacing with a back suffix) or opaque (surfacing with a front suffix).

(6) **Variability in Disharmonic Loanwords**
a.	hieroglyfi-a	∼	hieroglyfi-æ	'hieroglyph'
b.	analy:si-a	∼	analy:si-æ	'analysis'
c.	martty:ri-a	∼	martty:ri-æ	'martyr'
d.	sutenø:ri-a	∼	sutenø:ri-æ	'pimp'
e.	jonglø:ri-a	∼	jonglø:ri-æ	'juggler'
f.	amatø:ri-a	∼	amatø:ri-æ	'amateur'
g.	miljonæ:ri-a	∼	mijonæ:ri-æ	'millionaire'
h.	afæ:ri-a	∼	afæ:ri-æ	'affair'

Furthermore, the rate of selecting different variants is not constant across all phonological conditions. Ringen & Heinämäki (1999) conducted a study of 50 native speakers of Finnish, eliciting suffixed forms for disharmonic loanwords. The same speakers were tested twice, with one month between sessions. The table in (7) shows, for each item, the proportion of subjects whose choice of suffix — front or back — was inconsistent (either within a single session or between the two sessions). Because the vast majority of stable responses were front suffixes (opacity), an increase in variability means an increase in the likelihood of transparency.

(7) **Proportion of Subjects who Showed Variability**
High	($\bar{x} = .35$)
hieroglyfi	.26
analy:si	.48
martty:ri	.32
Mid	($\bar{x} = .18$)
sutenø:ri	.10
jonglø:ri	.18
amatø:ri	.26
Low	($\bar{x} = .12$)
miljonæ:ri	.04
hydrosfæ:ri	.08
afæ:ri	.25

Ringen & Heinämäki did not provide any statistical analysis, but a logistic regression on their data (as given above) shows that the effect of height is significant (Estimate=0.7091, SE=1.512, z=4.689, p=2.74e-06). The higher the vowel, the higher the likelihood that subjects would entertain the possibility of transparent harmony (selection of a back suffix) at least some of the time.

2.1. Sources of Explanation

There are several potential sources of explanation for this asymmetry. Nevins (2004) and Kaun (1995) suggest that the higher sonority (and hence longer duration) of lower vowels means that they constitute a greater interruption to the harmony domain. Benus (2005); Benus & Gafos (2007) propose that the quantal properties of vowels are responsible for similar facts in Hungarian (see e.g. Hayes et al. 2009; Hayes & Londe 2006 for a discussion of those facts) — high vowels' greater tolerance of transparency is attributable to their greater ability to undergo coarticulation without affecting their categorical perceptual identity.

These approaches can be compared with a theory of transparency and opacity in harmony which views the choice between competing harmony triggers — local on the one hand, and dominant on the other. Under this approach, the asymmetries seen in Finnish and Hungarian receive their explanation

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[1] A final epenthetic [i] is found when consonant-final loanwords are adapted; in loanwords, [i] is transparent, as it is in the native vocabulary.

from lower vowels' status as preferential triggers of front/back harmony; low vowels are more likely to be opaque because they are under more pressure to instigate their own feature domain.

Any of these explanations is sufficient to explain the fact that higher vowels in Finnish loanwords are more likely to be transparent than lower vowels. However, these three approaches make divergent predictions about the role of the phonological context beyond the transparent/opaque vowel itself. In particular, in a V_1–V_2–V_3 sequence, where V_2 is a potentially transparent or opaque non-participant, do properties of V_1 influence the likelihood that V_2 will be transparent?

A sonority-based explanation for the behavior of V_2 predicts that V_1 should not have any influence over the outcome, since V_1 has no impact on the sonority of V_2. An explanation based on the quantal properties of V_2 predicts that a more articulatorily extreme V_1 (in the case of front/back harmony, higher) should increase the likelihood of transparency — a more extreme V_1 will have a more pronounced coarticulatory influence on V_2, and a V_2 that has undergone more coarticulation for the harmonizing feature value is more likely to be transparent.

An explanation based on trigger competition predicts that, just as opacity is more likely when V_2 is a preferred trigger than when it's not, transparency is more likely when V_1 is a preferred trigger than when it's not. Because weakly cued segments are preferred triggers, this means that a weakly cued V_1 — in the case of front/back harmony, lower — should increase the likelihood of transparency. This is precisely the opposite of what an explanation based in the quantal properties of transparent and opaque vowels predicts.

2.2. Hypothesis

Of present interest are precisely the type of data that Ringen & Heinämäki (1999)'s experiment is concerned with — disharmonic loans with back–front vowel sequences. The generalization that higher vowels are more likely to be transparent than lower vowels is, as discussed in the introduction to this chapter, equally well explained by a number of different theories of transparency and opacity. Because Ringen & Heinämäki used real loanwords as their stimuli, their results are of limited use in determining what other factors influence the choice between transparency and opacity — the height and number of triggering back vowels, for instance, is not sufficiently manipulated to provide insight into its influence.

The present experiment uses nonce loanwords instead of real loanwords, to permit more detailed manipulation. Subjects are presented with disyllabic back–front loanwords, and asked to make a binary choice between a front suffix (opaque harmony) and a back suffix (transparent harmony). Height and length of both V_1 and V_2 were manipulated, providing the necessary data to test the diverging predictions of various explanations for asymmetries in transparency and opacity.

If the choice between transparency and opacity is a competition between potential harmony triggers, then the factors that contribute to the strength of *each* of those triggers is predicted to influence the outcome.

In other words, in a V_1–V_2–V_3 sequence, where V_2 is a potentially transparent or opaque non-participant, V_1 and V_2 are competing to determine the feature specification of V_3. In a disharmonic back–front loanword in Finnish, selection of a back suffix represents a victory for V_1 (transparency), while selection of a front suffix represents a victory for V_2 (opacity). If V_2 is a better trigger, then, it should be more likely to triumph than if it is a poor trigger, and hence the probability of opacity should increase. Similarly, if V_1 is a better trigger, it should be more likely to win, and the probability of transparency should increase.

The properties that make a segment a better or worse trigger are related to the factors that motivate harmony in the first place. Since harmony imparts a perceptual advantage by rendering difficult contrasts more salient (as was shown in Chapter 4), the segments that have the most impetus to spread their features are those whose perceptual cues for the relevant contrast are impoverished. Thus, segments with poor cues to the harmonizing feature should be preferred as harmony triggers.

Kaun (1995) shows that this explains asymmetries in trigger strength in various rounding harmony systems; low round vowels are produced with a less prominent rounding gesture than their high counterparts, and these are precisely the vowels which preferentially trigger harmony. The same explanation for triggering asymmetries can also be applied to Finnish — low vowels are less separated along the front/back dimension than their high counterparts, so low vowels should be preferred triggers

of harmony along the front/back dimension.

Since the trigger competition model predicts that transparency should be more likely when V_2 is a poor trigger than when it is a preferred trigger, and low vowels are comparatively perceptually impoverished along the front/back dimension (and hence better triggers), **transparency should be more likely when V_2 is high than when it is low**. This explains Ringen & Heinämäki (1999)'s results, which we expect to replicate in the present experiment. Furthermore, the trigger competition model predicts that transparency should be more likely when V_1 is a preferred trigger than when it is a poor trigger, so **transparency should be more likely when V_1 is low than when it is high**.

3. Methods
3.1. Stimuli

Stimuli for the experiment consisted of 36 $CV_1C.CV_2$ nonce words; in all conditions, V_1 was back and V_2 was front (and non-neutral). Height and length of both V_1 and V_2 were manipulated, in a fully crossed design — each possible V_1 (a, a:, o, o:, u, u:) was paired with each possible V_2 (æ, æ:, ø, ø:, y, y:).[2]

The CVC.CV shape was chosen to prevent interactions between initial vowel length and durational effects of stress on non-initial vowels (in CV.CV words only, V_2 shows an increase in duration under V_1 stress; see Suomi et al. 2008 for more details).

The consonants [p,t,k,s,f] were used; the inclusion of [f] in particular was intended to encourage subjects to interpret the nonce items as plausible loanwords, since [f] is not present in the native inventory but is permitted in loanwords. Additionally, a randomly selected half of the medial CC sequences were geminates, and the remainder were heterorganic clusters.

In addition to the test items, 6 additional nonce words were included to serve as catch trials. These again were CVC.CV in shape, using the same consonant inventory, but half consisted of back–back sequences and half consisted of front–front sequences. Because behavior on items of this type is categorical and fully predictable, these items can serve as controls and can be used to determine whether or not subjects are participating in good faith in the task.

3.2. Task

The experiment was delivered over the internet, using the online survey administration software LimeSurvey. Because the phoneme-to-grapheme relationship in Finnish faithfully represents the relevant vowel contrasts, stimuli were presented orthographically rather than auditorily.[3]

Subjects were presented with a frame sentence with a blank, and asked to make a binary choice between a nonce item with a front suffix and that same item with a back suffix. An example of the task is given in (8). The suffixes used were [-ssa/-ssæ] ("in") and [-sta/-stæ] ("of/from") — both the choice of suffix and the order of presentation of the front/back versions was counterbalanced.

(8)   Prosessissa tarvittava kemiallinen liuos valmistetaan[4] _____

     a. puktyssa
     b. puktyssä

The frame sentences chosen centered thematically around chemistry and chemical combinations, to further encourage subjects to treat the nonce items as novel loanwords. Each nonce word was paired consistently with its own frame sentence, and all subjects saw each item once; this resulted in a survey that took subjects approximately 10 minutes to complete.

To mitigate any prescriptive influence, subjects were explicitly instructed to make their choice based on what sounded best to them, rather than on what they might think is the "correct" choice.

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[2] One item (Co:C.Cø:) suffered from a typo (presented as Cø:C.Cø:) — it was analyzed as an additional catch trial. The statistical analysis of the results should still be robust in the face of the missing cell.

[3] In some English-based loanwords, there is a phoneme/grapheme mismatch — however, this is likely an inherited mismatch from the source language, and subjects appear to be defaulting to orthography in the absence of a given alternate pronunciation.

[4] "The chemical solution needed in the process is made of..."

Prop. Transparency by V1 Height   **Prop. Transparency by V2 Height**
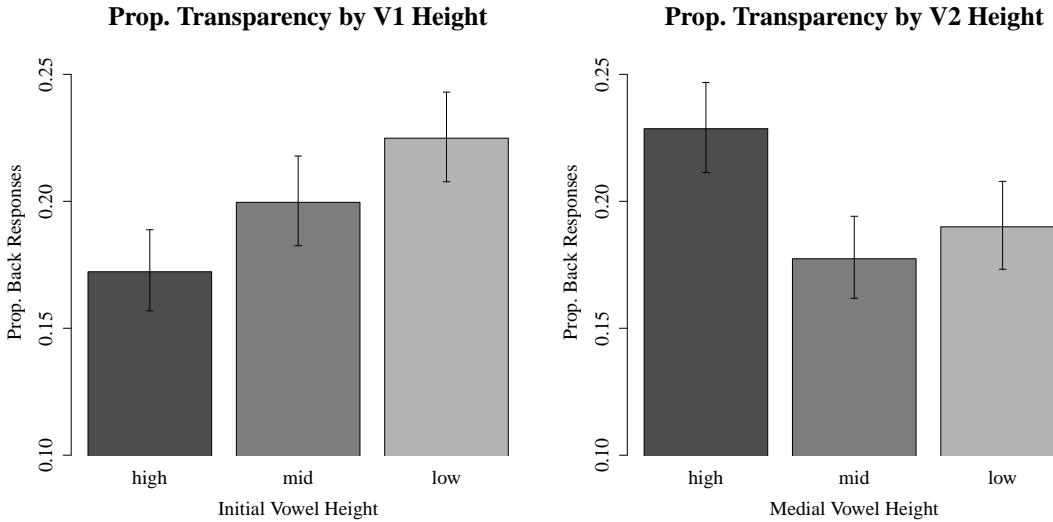

Figure 1: Proportion of back suffix responses by initial vowel height (left) and by medial vowel height (right). Error bars represent binomial confidence intervals (95%).

3.3. Subjects

Subjects were recruited via a post in a Finnish Knitters forum on the knit/crochet based social networking site Ravelry. The survey remained active for approximately two days; 285 subjects started the survey, and 209 completed all questions. Respondents were nearly all female, and reported locations from all over Finland.

Of the 209 subjects who responded to all survey items, data was analyzed for only those who reported that they were native speakers of Finnish and responded incorrectly on at most one of the catch trials. A total of 179 subjects met these criteria.

Informal feedback collected from responses to the original forum post indicated that subjects found the task difficult. A number of respondents indicated that they felt that the frontness or backness of the vowels in the words was relevant, but many had incorrect intuitions about which vowels were front and which were back. None reported adopting any consistent strategy for determining the correct response.

Though the subjects were not compensated for their time, many reported deriving considerable enjoyment from the task. After the survey was deactivated, a number of potential subjects expressed disappointment at having missed their opportunity to participate.

4. Results

The variable we are interested in is the proportion of subjects who preferred transparent harmony (versus the proportion of subjects who preferred opaque harmony). Because all of the test items consisted of back–front vowel sequences, selection of a *back* suffix is indicative of transparency, while selection of a *front* suffix is indicative of opacity.

The proportion of transparent responses, as a function of V_1 height and V_2 height, is plotted in Figure 1. Overall, subjects showed a preference for opacity — front suffixes were substantially more frequent than back suffixes, across all conditions. Furthermore, both V_1 and V_2 height have an impact on the proportion of transparent responses. In the figure on the left, we see that transparency is more likely with a mid V_1 than with a high V_1, and even more likely with a low V_1. In the figure on the right, we see that transparency is more likely with a high V_2 than with a mid or low V_2, but mid and low V_2 pattern similarly. In Figure 2, proportion of transparent responses is plotted as a function of V_1 length and V_2 length. For both V_1 and V_2, subjects were more likely to choose transparency with a short vowel than with a long vowel.
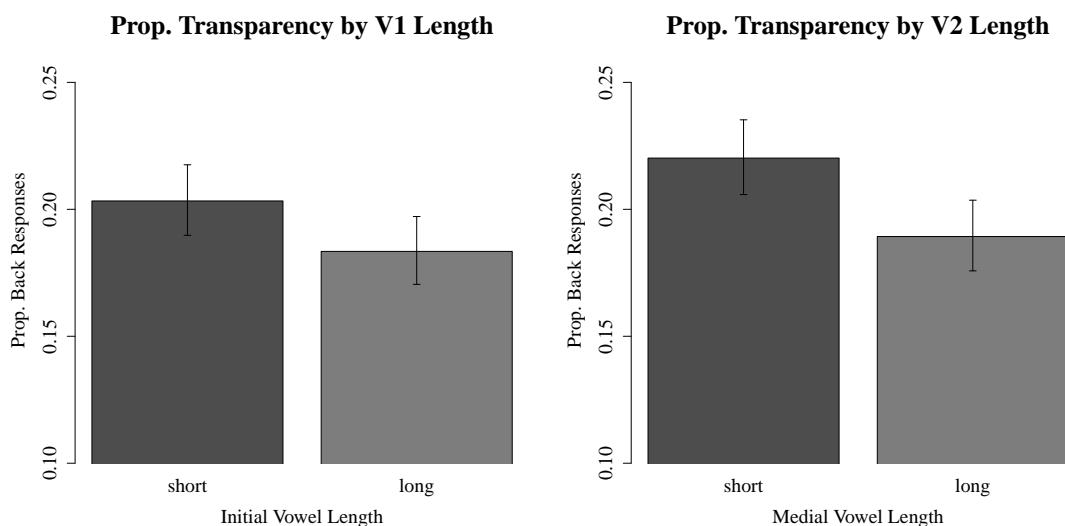
Figure 2: Proportion of back suffix responses by initial vowel length (left) and medial vowel length (right). Error bars represent binomial confidence intervals (95%).

A generalzed linear mixed effects model was fitted, using the `lme4` package (Bates & Maechler, 2010) in R (R Development Core Team, 2009), with back responses as the dependent variable, V_1 height, V_1 length, V_2 height, and V_2 length as predictors, and random effects for subjects. Vowel height is treated as an ordered factor — the three levels (low, mid, high) are in an ordinal relationship, as mid vowels are articulatorily and acoustically intermediate between high and low vowels, but there is no *a priori* reason to believe that the distance between low and mid vowels is the same as the distance between mid and high vowels. As an ordered factor, height is given orthogonal polynomial contrast coding.

The effects of height were significant for both V_1 and V_2; for V_2 height, both the linear (z = 3.617, p < 0.001) and quadratic (z = –3.746, p < 0.001) terms were significant; for V_1 height, the linear term was significant (z = –5.339, p < 0.001), but not the quadratic term (z = 0.315, p = 0.75). In other words, the likelihood of transparency increases as V_1 height decreases, and this increase is linear. On the other hand, the likelihood of transparency decreases as V_2 height decreases, but this decrease is not linear. The significance of the quadratic component for V_2 height reflects the behavior of mid vowels we saw in Figure 1.

Furthermore, the effect of V_2 length was significant (z = 4.989, p < 0.001), but the effect of V_1 length was not (z = 1.018, p = 0.31). In other words, the length of V_1 did not have an impact on the likelihood of transparency, but transparency was more likely if V_2 was short than if it was long.

5. Discussion

The results presented in Section 4 support the predictions of the trigger competition approach — in particular, the finding that the likelihood of transparency is greater with lower vowels supports trigger competition to the exclusion of other proposed explanations for transparency/opacity asymmetries.

Because lower vowels are more poorly cued along the front/back dimension than their high counterparts, they have a greater impetus to spread their feature value and reap the perceptual rewards of harmony. Because V_1 and V_2 are competing to spread their value for the feature onto V_3, both V_1 and V_2 should be more likely to win when they are preferred triggers than when they are poor triggers. Thus, a victory for V_1 (transparency) should be more likely when V_1 is low than when it is high — similarly, a victory for V_2 (opacity) should be more likely when it is low than when it is high (meaning that, in turn, transparency should be less likely when V_2 is low than when it is high). This is precisely what the experimental results show to be the case in Finnish.

At first glance, the results for vowel length appear to support a sonority-based explanation over one situated in trigger competition — V_1 length had no significant effect, while for V_2, transparency was more likely for short (less sonorous) vowels than for long vowels. If weakly cued segments are

better triggers, short vowels should be preferred as triggers; long vowels' increased duration provides more robust cues for vowel features. Therefore, short vowels in V_1 position should result in a greater likelihood of transparency than long vowels, and short vowels in V_2 position should result in a decreased likelihood of transparency.

While the contribution of V_1 length did not reach statistical significance, the numerical trend is in the direction predicted by the competing triggers account — transparency was slighly more likely with a short V_1 than with a long V_1. The results for V_2 length at first appear to be more troubling; the effect is significant, but in the wrong direction. Short vowels should be preferred as triggers, and hence should result in decreased likelihood of transparency, but in fact they are *more* likely to be treated as transparent than their long counterparts. However, these results are expected if we consider the fact that intrinsic segmental properties are not the only source of trigger strength — in fact, crucial to the account of transparency and opacity is the notion that non-local triggers are worse triggers, and increasing degrees of non-locality result in an increasingly bad trigger. Long vowels, which are both durationally and representationally longer than short vowels, result in an increased degree of non-locality. Thus, transparent harmony across a long vowel is *less local* than transparent harmony across a short vowel, and should in fact be less likely, as the results show.

The competing triggers account predicts an effect for V_1 length which does not reach significance in the experimental results. The fact that there is a numerical trend in the predicted direction can't be said to count in *favor* of this approach, but also cannot necessarily be said to count *against* it. On the other hand, the sonority-based approach predicts that no properties of V_1 should have an influence, yet V_1 height is a significant predictor.

A comparison was made between the generalized linear mixed effects model described above (Model 1: V_1 height, V_1 length, V_2 height, and V_2 length as predictors) with one which omitted the V_1 parameters (Model 2: only V_2 height and V_2 length as predictors). Model 1 performed better than Model 2 on AIC (Model 1 = 4556.4, Model 2 = 4579.8), BIC (Model 1 = 4610.3, Model 2 = 4613.5) and log likelihood (Model 1 = -2284.9, Model 2 = -2270.2). A χ^2 test found the difference between the two models to be significant (χ^2 = 29.45, p < 0.001).

These model comparison tests penalize including additional factors, but reward the increase in explanatory power that comes from inclusion of significant predictors. Model 1 represents the predictions of a trigger competition account; V_1 length and height are both included, even though V_1 length is not significant, because the theory predicts that they should have an influence over the outcome. Model 2 represents the predictions of a sonority-based account; no V_1 parameters are included, because these are not predicted to have an effect. In comparing these two models, we see that the explanatory value of including V_1 height as a predictor appears to be worth the cost of including V_1 length as a non-significant predictor. In other words, while neither set of predictions is perfectly matched, a trigger competition model provides a better account of the data than a sonority-based account.

The account that Benus (2005); Benus & Gafos (2007) propose, however, does have the ability to predict that the properties of V_1 can influence the choice between transparency and opacity — however, those precitions would be that the effect should be in the opposite direction. Transparency is predicted to be more likely when V_1 is high than when it is low, contrary to the effect found in the experimental results above.

For Benus & Gafos, transparency is in fact a form of participation. A non-participating V_2 is unable to undergo categorical alternation, but does undergo sub-phonemic coarticulation — that is, because an [i] following a back vowel coarticulates with its neighbor, it is less front that an [i] followed by a front vowel. This retraction, in turn, predicts whether V_3 will be front or back; a sufficient degree of sub-phonemic retraction on V_2 induces categorical backness on V_3. Factors which increase the degree to which V_2 coarticulates, then increase the probability of transparency.

Under this account, the asymmetries in V_2 height are due to non-linearities in the relationship between articulation and perception. According to quantal theory, [i] is in a zone of relative perceptual stability as compared to lower front vowels, and can therefore tolerate a greater degree of articulatory variability without affecting its perceptual identity as a front vowel. Lower vowels, because they are closer to a region of comparative instability, can tolerate relatively less articulatory variability if they are to remain perceptually identifiable as front vowels. As a result, a high non-participating V_2 can undergo more articulatory retraction following a back vowel than a mid or low V_2 — because more

retraction means a greater probility of transparency, this explains why high vowels are more likely to be transparent. Benus & Gafos use this difference in degree of retraction to explain why hungarian [e] is less likely to be transparent than [i], and also to explain why a sequence of two [i] syllables is optionally opaque (the coarticulatory effect has a diminished influence on the second [i] in the sequence, resulting in a lower likelihood of transmitting backness to a subsequent suffix).

Benus & Gafos do not discuss the effects of V_2 length, but those can also be explained via influence on the degree of coarticulation. Because greater vowel duration means more time to fully reach an articulatory target, a long [i] should undergo less coarticulation, and should be less retracted than a short [i]. In turn, because long vowels will be less retracted, they should be less likely to induce backness on a following vowel and therefore should be less likely to be transparent than their short counterparts — the effect here is similar to distance effect shown by sequences of multiple transparent vowels. This is precisely the effect we see in the Finnish data.

Benus & Gafos also do not discuss the role of V_1, but their explanation for the other effects does provide a way of predicting what the effects should be. Higher vowels are more extreme in their articulation along the front/back dimension than lower vowels — high vowels, therefore, should exert more coarticulatory influence over the following vowel than their low counterparts, since reaching a front target requires greater articulatory movement when coming from a more extreme back vowel. This increased degree of coarticulation, in turn, should mean a greater likelihood of transparency. In other words, transparency should be more likely when V_1 is high than when it is low — in fact, however, Finnish subjects were more likely to choose transparency when V_1 was low than when it was high.

A similar reasoning applies when predicting the effect of V_1 length. Because a longer vowel means that a more extreme articulatory target is possible, a longer V_1 should induce more coarticulation on V_2 than a shorter vowel. This in turn should induce a greater likelihood of transparency, predicting that transparency should be more likely when V_1 is long than when it is short. There was no significant difference between long and short V_1 in the experimental results, however the numerical trend was in the opposite direction from these predictions — short vowels were slightly more likely to induce transparency than long vowels.

A side-by-side comparison of the predictions of the three models with the experimental results is given in (9). All three models successfully account for the V_2 results for height and length, but diverge with respect to V_1. Because V_1 length did not reach significance, it is not particularly useful in choosing among the theories; the lack of effect is predicted by the sonority-based account, and the numerical trend in the data is predicted by the trigger comparison account. V_1 height showed a clear, significant effect, so it is perhaps more useful — and clearly favors a trigger competition approach.

(9) **Attested vs. Predicted Likelihood of Transparency**

	V_1 Height	V_1 Length	V_2 Height	V_2 Length
a. Exp. Results	**hi < lo**	**short = long**	**hi > lo**	**short > long**
b. Sonority	hi = lo ✗	short = long ✓	hi > lo ✓	short > long ✓
c. Quantal Theory	hi > lo ✗	short < long ✗	hi > lo ✓	short > long ✓
d. Trigger Comp.	hi < lo ✓	short > long ?	hi > lo ✓	short > long ✓

To conclude, of the three approaches to explaining asymmetries in transparency and opacity, the trigger competition approach best accounts for the qualitative patterns in the results of this experiment. In particular, this approach uniquely predicts that lower vowels in V_1 should result in a greater likelihood of transparency, an effect which is present and robustly statistically significant in the experimental results. The results of the experiment presented in this paper therefore consitute compelling evidence in favor of a trigger competition approach to transparency and opacity in harmony.

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Proceedings of the 30th West Coast Conference on Formal Linguistics

edited by Nathan Arnett
and Ryan Bennett

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This paper can be cited as:

Kimper, Wendell and Riikka Ylitalo. 2012. Variability and Trigger Competition in Finnish Disharmonic Loanwords. In *Proceedings of the 30th West Coast Conference on Formal Linguistics*, ed. Nathan Arnett and Ryan Bennett, 195-204. Somerville, MA: Cascadilla Proceedings Project. www.lingref.com, document #2817.