The Odd Yearbook 8 (2010): 111–137, ISSN 2061-4896

Vowel centralization and vowel harmony in Hungarian*

Szeredi Dániel

1 INTRODUCTION

This paper presents a number of experiments to show the existence of vowel reduction in Hungarian, and to prove that vowel harmony affects the behavior of this pattern. I argue that the examination of this phenomenon, which has been neglected because of its allegedly non-phonemic and therefore non-linguistic status, is important as some recent theoretical frameworks argue for the importance of phonetic facts in phonological analyses.

Section 2 presents previous research that has been done on Hungarian vowel reduction and the theoretical background of functionally based phonology. Sections 3 and 4 describe the set-up and the results of an acoustic and a perceptional experiment, that test the existence and perceptional relevance of vowel undershoot in Hungarian. These experiments prove that Hungarian vowel reduction shows a unique pattern, as the frontness of the vowel determines the target of reduction. Section 5 presents different analyses to describe this pattern and argues that it is possible to find a theoretical approach (that of Schwartz et al. 1997 and Harris 2005) that can provide an explanation for the peculiarities in the Hungarian reduction pattern. Finally, in section 6, I argue for the relevance of vowel harmony in the description of the vowel undershoot pattern in Hungarian.

2 BACKGROUND

2.1 On vowel reduction

The phonetic phenomenon of vowel reduction or vowel undershoot is commonly described as the articulatory failure of a peripheral vowel to reach the 'canonical' target position for the given segment (Lindblom 1963; Clark et al. 2007). This means acoustically that the duration of the vowel is shorter, and lower intensity and certain changes in vowel quality follow. In many languages like English, Danish and Portuguese, this process is phonologized and obligatory, which means that it is no longer vowel undershoot,

*I would like to thank Márton Sóskuthy, Zsuzsa Bárkányi, Sylvia Blaho, Zoltán Kiss, Péter Rácz and Péter Siptár for providing me help and suggestions for this article and Brigitta Fodor for her support and patience.

but a language-specific set of constraints limiting the occurrence of certain vowels in certain environments.

This phonologized pattern of vowel reduction is a well described phenomenon. There are two types of reduction patterns found in the languages of the world (Crosswhite 2004; Harris 2005): prominence reduction, or *centripetal* reduction, which means that vowels centralize towards [ə] and contrast-enhancing, or *centrifugal* reduction, where vowels tend to be neutralized in the corner vowels [a, i, u], that cannot be ascribed to mere articulatory undershoot.

Harris (2005) shows that there are centralization patterns that mix these two types of reduction, and therefore a more detailed functional analysis is needed to describe them. One of the main findings of the present paper is that Hungarian shows a subphonemic vowel reduction pattern that is of this mixed type. An important hypothesis of this paper is that a non-phonologized, that is, subphonemic vowel reduction pattern like this is also worth exploring and that it can also be described using the frameworks intended for the analysis of phonemic vowel reduction. The other hypothesis is that an appropriate analysis can explain the mixed behavior of the Hungarian vowel reduction pattern by pointing out the role of vowel harmony in this language, and explaining why vowel harmony can skew a centripetal vowel undershoot pattern.

The main variables for testing vowel reduction throughout this paper will be the first two formant values. The reason for this is that vowel length is lexicalized in Hungarian but its phonetic realization is variable and disputed (Mády & Reichel 2007), pitch is determined by syntactic and pragmatic factors (Varga 2002), and the role and importance of intensity and stress in Hungarian is also not clear (Blaho & Szeredi 2009). The third formant has been examined in certain environments, and it will be discussed when it seems to be relevant.

In the experiments presented in this paper, phonetic analyses were done using Praat (Boersma & Weenink 2010). Statistical analysis was carried out using the open source R software (R Development Core Team 2009).

2.2 Previous research on Hungarian vowel undershoot

Textbooks for foreigners usually contain the assertion that there is no vowel reduction in Hungarian; moreover, they usually claim that every Hungarian vowel is pronounced distinctly and clearly, which should mean they are not to be pronounced in a reduced or centralized form. The following is a typical example: ‘Die Betonung des Wortes liegt immer auf der ersten Silbe. Die Vokale werden aber auch in allen folgenden Silben voll und klar ausgesprochen.' [The stress of the word always falls on the first syllable. But vowels are pronounced full and clear in every following syllable.] (Ginter & Tarnói 1974/1993: 11). The prescriptivist tradition also holds that a distinct and clear pronunciation of speech sounds is typical for Hungarian, contrary to other languages, and 'blurring' segments is a maleficent effect of modern life in these other languages (e.g. Benkő 1992).

However, reduced or centralized vowels do occur on the surface, but their distribution and frequency have not been sufficiently researched (Ács & Siptár 2001). de Graaf (1987) confirmed in an auditory experiment with two speakers that vowels do centralize towards [ə] in Hungarian, and that the extent of centralization is dependent on its context: free vowels are less reduced than vowels in isolated words and much less reduced than vowels in context.

Gósy (1997) has carried out an experiment where the continuous speech of a male speaker with average voice parameters and no speech defects was recorded. Several vowels were cut out from the signal and these short isolated sound segments were played back to 10 participants, who were asked to transcribe the sound they had heard in Hungarian orthography. When they categorized any vowel that is not underlying /ø/ as <ö>, which was supposed to be the sound acoustically closest to schwa, it was posited that the sound they heard was actually schwa, or at least a largely centralized vowel. It was found that 49.3% of non-/ø/ phonemes had been transcribed az <ö>, implying that there might be a large proportion of centralized vowels on the surface in non-formal Hungarian speech.

Gósy (2006) merely elicits the types of schwa-like sounds occuring in any type of phonetic environment in Hungarian. She lists the reduced [ə] without citing any further research on the reduction process, and also takes into account schwa-like sounds like the voiced release occuring after the burst of utterance-final plosives and between taps in trilled [r] sounds.

2.3 The relevance of subphonemic phenomena in theoretical linguistics

Subphonemic processes have not been seen as relevant to phonology or phonological theory. There are reasons, however, that one might approach subphonological data using phonological accounts developed to explain phonological phenomena.

Subphonemic variation that had been previously treated as irrelevant for language has become more important in theoretical frameworks that do not attempt to explain universal features in languages by referring to an innate Language Faculty. Diachronic approaches such as that presented in Blevins (2004) are based on the assumption that the universal features of languages follow from the diachronic nature of language: languages share similar traits because the way they change is similar, so constraints on synchronic phenomena can be traced back to constraints on diachronic processes. This means that, contrary to the generative tradition where universals are explained through the innateness hypothesis and the assumption of the existence of a Language Faculty, there is no need for such a (from a certain point of view) extra-linguistic explanation and constraints on synchronic phenomena can be traced back to constraints on diachronic processes, that can, and should be described inside the domain of linguistics.

This also means that *synchronic* phonological accounts that are able to account for patterns found in the subphonemic domain like vowel reduction in Hungarian should be preferred over those that are not, because subphonological behavior in a generation is the source of the phonological patterns of a later generation. Ohala (1981) describes how the listener, and in an acquisitional point of view, the learner could also be the source of sound change in some scenarios. These scenarios attribute a crucial role to subphonemic patterns, and Ohala describes how these patterns can lead to a *phonological* shift in the next generation.

Functional approaches using exemplar-based rich lexicon models like Bybee (2001); Pierrehumbert (2001) also rely on phonetic forms that are stored in the lexicon and claim that categories evolve or emerge based on these forms. Subphonemic variation is equally important to these approaches as well, as various linguistic processes are explained by analogy and interaction between items stored in memory in these frameworks, which rely on the knowledge of the phonetic forms of a given lexical item or 'phonological' unit.

3 THE ACOUSTIC EXPERIMENT

3.1 Set-up

The acoustic experiment (first described in Szeredi 2008) was designed to test the following hypotheses:

- centralization is found in casual natural speech, affecting both the F1 and F2 formants
- the rate of centralization correlates with stress: the more stressed the vowel, the less centralized it is
- the pattern of centralization resembles the way this kind of process works in other languages, so some kind of theoretical model could explain the results, and this model could make some predictions about the behavior of other Hungarian vowels

Seven native speakers of Educated Colloquial Hungarian (Siptár & Törkenczy 2000), all between 21 and 28 years old, took part in the experiment. 14 sentences were recorded from each participant six times in a row, so for the later sessions the register they used was more casual. The aim of the experiment was to investigate four environments under three different stress conditions. The four environments were (z) [tɒz], (a) [ʃɒk], (o) [hoɟ] and (e) [kɛɟ]; and the vowels in these sequences were of the following types: (1) primary stressed – that is, the first syllable of a content word; (2) unstressed as the last syllable of a content word and (0) unstressed in function words. After these reading sessions, 12 words were recorded from each participant, with the instruction to read these words slowly and carefully to attain the formants for slow careful speech vowels (g). The test sentences and words are listed in Appendix A.

Unfortunately, the sessions were not conducted in the best environment, but a silent room was available for the recordings. The audio files were sampled at 44100 Hz, and resampled at 10000 Hz for males and 14000 Hz for females. Five formants were measured with an upper threshold of 5000 Hz for males and 7000 Hz for females. Each vowel was examined at the point of the highest intensity. The measured vowels obviously showed the coarticulatory effect of neighboring consonants so additional tests had to be carried out to check if these had a significant effect on the results. In the following sections, only F1 and F2 will be discussed as F3 does not show any significant change dependent on stress in any of the examined environments. This formant will be discussed, however, in the analysis of the different behavior of the (a) and (z) environments as it has a significant role there.

The relevant vowels are defined in Hungarian phonology as (cf. Siptár & Törkenczy 2000: 51–52):

[ɒ]: a low back rounded vowel; however it is often characterized as [ɔ]

[ɛ]: a low front non-rounded vowel, which is in contrast with [eː] and [aː]

[o]: a mid back rounded vowel

3.2 Results

3.2.1 The phoneme /ɛ/

Figure 1 shows the average position of the careful speech vowels and the average position of the vowels in the (e1), (e2) and (e0) environments in faster, casual speech.

The second formant of the /ɛ/ phoneme does not show centralization. The careful speech mean is 2086 Hz, which is not significantly different

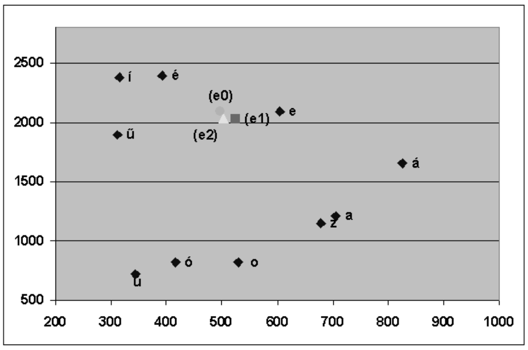

Figure 1: *Average positions of vowels in environments with phoneme /ɛ/*

from casual realizations, where the overall mean is 2052 Hz (t = 0.6014, d.f. = 20 yields $p > 0.55$). The t-test shows no significant differences for different stress positions either: $p > 0.97$ for (e1)~(e2), $p > 0.71$ for (e2)~(e0) and $p > 0.68$ for (e1)~(e0). However, this can be attributed to the effect of the neighboring palatal /ɟ/ consonant, which can hinder the velarization of the preceding vowel. This result is also somewhat surprising considering the analysis of de Graaf (1987), who finds the short vowel [ɛ] to reduce its F2.

The first formant of the vowel in this environment shows centralization: it is almost always higher than the F1 of the vowel in careful speech (the careful speech mean is 604 Hz and the casual speech mean 508.24; t = 7.7645 with d.f. = 20 yields $p < 0.001$). The only exception is the fifth speaker, who read the (eg) environment as a mid-high [e], either because of emphatic or dialectal pronunciation, so their (e1), (e2) and (e0) vowels are more open and more centralized. However, these environments were pronounced in the same way as they were by the other speakers. Another peculiarity is that the (e0) variable of one speaker is very open, pronounced as [æ]. In other recordings of the speech of this speaker, the vowel is mid-high, like the (e0) of other speakers. Since this vowel is very short – only about 20 ms – this phenomenon can be attributed to the fact that the formants show the impact of neighboring consonants.

The hypothesis about the correlation between the degree of centralization and that of stress does not seem to be correct in the case of /ɛ/, as the realizations of the vowel in this environment are approximately in the same place along the dimensions of the first three formants, as it can be seen in the boxplot in Figure 2. The t-test shows no significant difference: $p > 0.45$ for (e1)~(e2), $p > 0.91$ for (e2)~(e0) and $p > 0.44$ for (e1)~(e0); that is, all of them are pronounced as [e̞] or [ɪ] in casual speech.

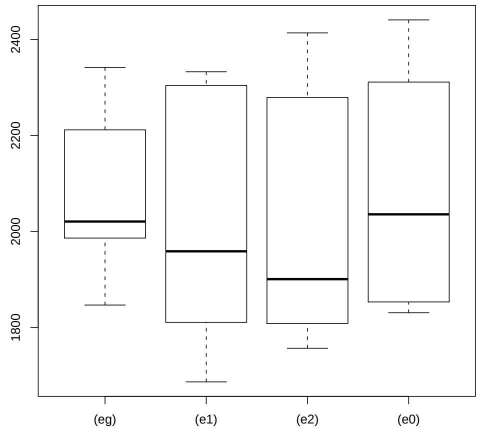

Figure 2: *F2 values for the vowel /ɛ/ aggregated by stress position.*

3.2.2 The phoneme /o/

As it can be seen in Figure 3, the realizations of the phoneme /o/ behave in the opposite way to the realizations of /ɛ/. The first formant does not undergo centralization in casual speech (t = 0.0903, with d.f. = 20 yields p > 0.92). This is quite easily explained, as the careful speech (og) environment usually has a mid, or centralized F1 itself, so no more centralization is possible. However, the second formant shows significant centralization, and this process is indeed related to the lack of stress as it was proposed in the hypotheses, so the stressed (o1) environment usually has a low F2 but (o2) is more centralized and (o0) in the function word *hogy* 'that (complementizer)' has a quality quite close to [ə], as shown in Figure 3 and summarized in Table 1 and the boxplot in Figure 4.

STRESS VAR	MEAN F2	SD F2	P VALUE
(og)	821	100	
(o1)	1102	73	p < 0.001 (o1)∼(og)
(o2)	1378	277	p = 0.039 (o2)∼(o1)
(o0)	1491	317	p = 0.495 (o0)∼(o2)

Table 1: *Mean F2 values for the vowel /o/*

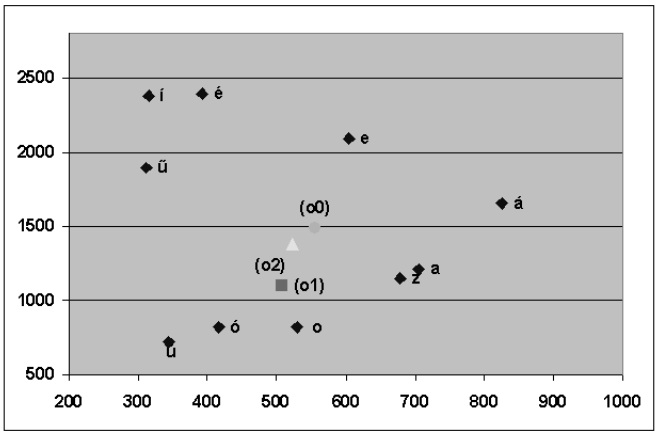

Figure 3: *Average positions of vowels in environments with phoneme /o/*

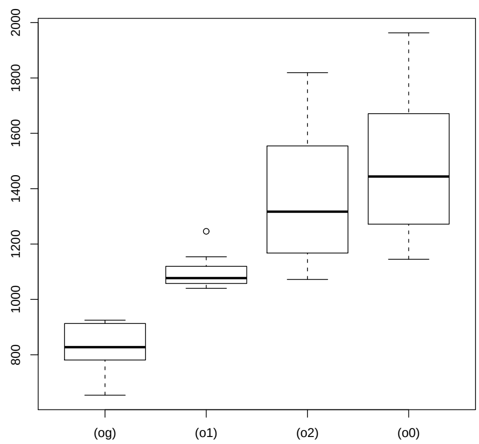

Figure 4: *F2 values for the vowel /o/ aggregated by stress position.*

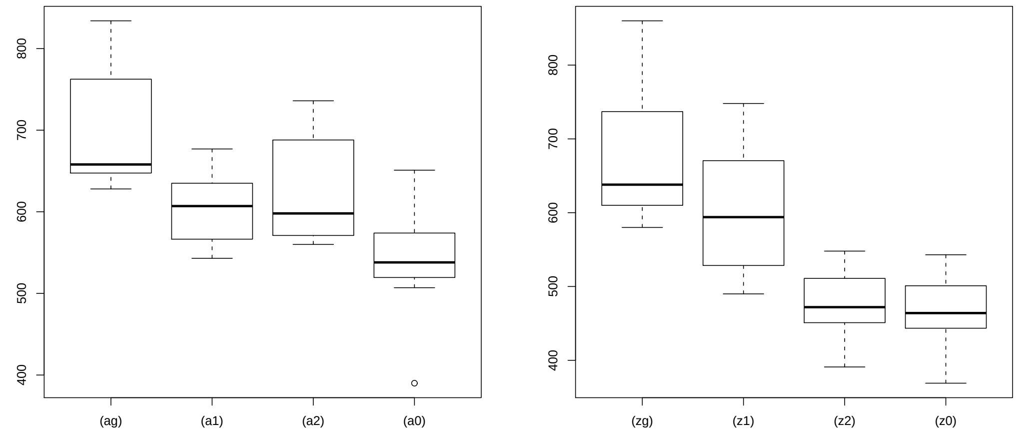

Figure 5: *F1 values for the vowel /ɒ/ in the two environments (a) and (z) aggregated by stress position.*

The environment of this vowel in the experiment is also a palatal /ɟ/, so it is possible that the fronting is affected by this consonant. If this was the case, an explanation for the graduality of centralization could be that the less stressed the vowel is, the shorter it is, thus the neighboring palatal consonant has a greater effect on its formants. However, the fact that no instances of underlying /ɒ/ stood beside palatal consonants but they still showed centralization, suggests that the effect of /ɟ/ cannot be the only factor in this fronting process.

3.2.3 The phoneme /ɒ/

The /ɒ/ phoneme shows the most typical schwa-oriented centralization, as both of its formants undergo this process in casual speech. This phoneme was examined in two environments to see the extent of centralization in both versions of the definite article (/ɒ/ and /ɒz/). The F1 of these vowels becomes lower as the degree of stress decreases as can be seen in Figure 5. The centralization of /ɒ/ in F2 is less gradient as the careful speech variant is significantly more back than the casual speech variant ($t \approx 7.8$, d.f. = 20 yields $p < 0.001$ for both environments), but there is no significant difference for stress environments in the casual realization of the vowel (cf. Figure 6).

The different behavior of the two environments can be seen in Table 2, and in Figures 7 and 8 as well. There is a significant difference between the

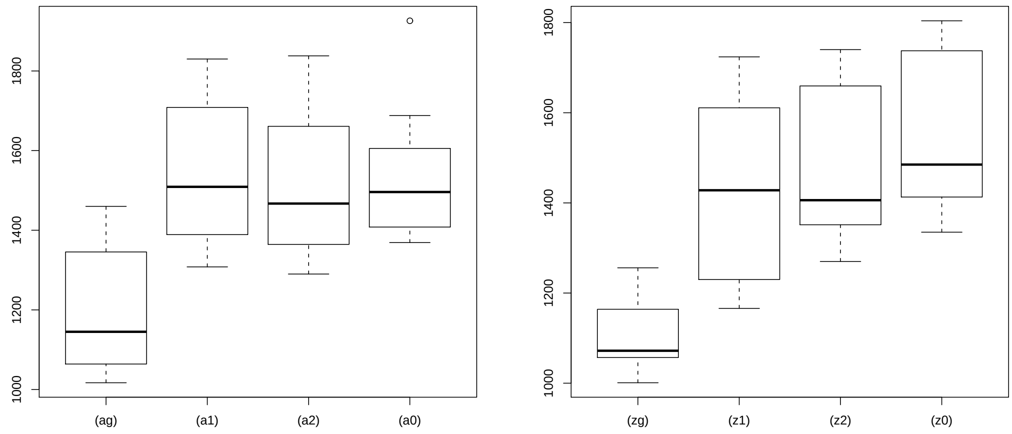

Figure 6: *F2 values for the vowel /ɒ/ in the two environments (a) and (z) aggregated by stress position.*

F3 values for these two vowels: it is much higher in the [tɒz] environment, nearing the value for non-rounded vowels. Whether the effect of the [t_z] environment is in fact a loss of rounding is an interesting question to be addressed in future research. Lowering of F1 (i.e. *raising*) is also significantly more prevalent in the (z) environment (paired t-test, t = 2.8169, d.f.=38.509 yields p $\approx$ 0.008), and reduction in vowel length also seemed to be stronger for the (z) environment. This reduction was so strong that some speakers had only one or two records out of six with an observable vowel segment in the (z0) environment.

VARIABLES	F1	F2	F3
ag-zg	**67**	48	**−180**
a1-z1	0	120	−191
a2-z2	**153**	29	−182
a0-z0	71	−15	−206
a-z all casual	**75**	44	**−193**

Table 2: *Differences (in Hz) between formants of vowels in* [ʃɒk] *(a) and* [tɒz] *(z) environments (bold values indicate a significant difference)*

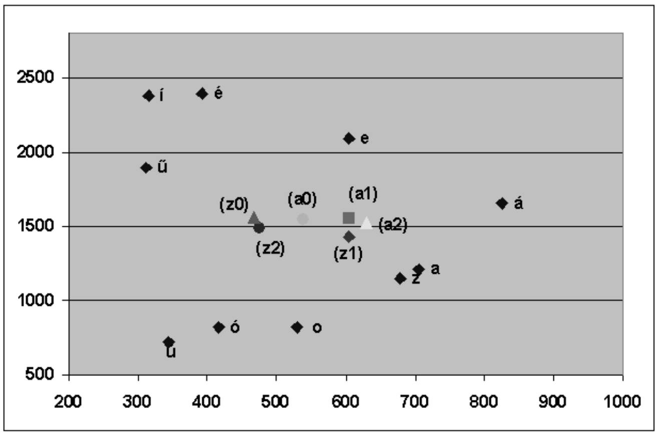

Figure 7: *Average positions of vowels in environments with phoneme /ɒ/ along the dimensions of F1 and F2*

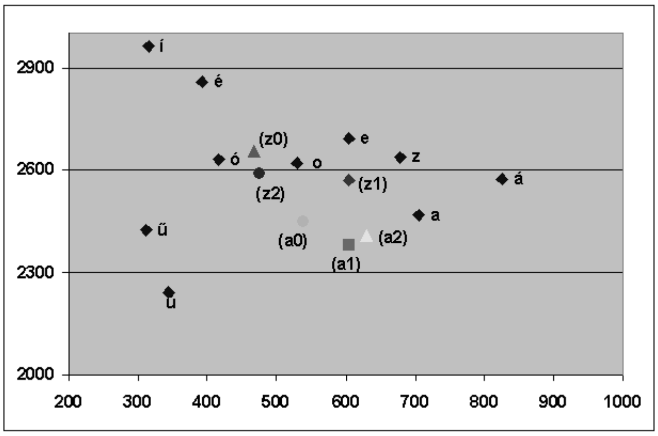

Figure 8: *Average positions of vowels in environments with phoneme /ɒ/ along the dimensions of F1 and F3*

	(a)	(z)	(e)	(o)
(g)	ɒ̞	ɒ̞	ɛ	o
(1)	ɐ̹	ɐ	ɪ	o̟
(2)	ɐ̹	ə̞	ɪ	ə̠
(0)	ə̹	ə̞	ɪ	ə

Table 3: *Average vowel qualities in the tested environments*

3.2.4 Summary

The results have shown that it is clear that Hungarian speakers tend to centralize vowels in certain positions. It can be seen that back vowels do centralize their formants towards [ə], and they show the expected graduality of reduction dependent on stress position. The front vowel [ɛ], however, fails to do so; no stress effect has been found, and there is no significant F2 lowering:

- F2 centralization

  (o): gradient fronting occurs as the vowel loses stress

  (a) and (z): gradient raising and shortening as the vowel loses stress, fronting in casual speech

- No F2 centralization

  (e): no backing, but F1 raising in casual speech under all settings of the stress parameter

The average tendencies of the vowels examined are summarized in Table 3.

These results are somewhat problematic as the extent of the effect of neighboring consonants is not clear. However, a series of follow-up experiments have confirmed the above findings in other environments. Rácz & Szeredi (2009) have shown that [o] is centralized towards [ə] in non-palatal environments such as [tok], [kot], [toʃ], [doʃ] and [dok]. As for the raising and the lack of centralization for [ɛ], Blaho & Szeredi (2009) have shown the same effect in environments like [fɛl], [lɛk], [kɛz], [zɛt], [mɛg], but found significant centralization for certain speakers towards [ə] in the context [lɛg], [nɛɦ], [ɦɛz] and [zɛb] in the word *legnehezebb* 'heavy.SUPERLATIVE'.

4 THE PERCEPTION EXPERIMENT

4.1 Set-up

The aim of the experiment presented here was to see if the F2-based dichotomy seen above is found in perception as well, because if it is, it might also prove that subphonemic processes might affect phonological categories, be influenced by the phonological system of a language and therefore also possibly influence the phonology of the language as predicted by functional approaches.

The pilot study presented here was conducted with 3 native speakers of Educated Colloquial Hungarian, who had to assign an acceptance score to test sentences. These test sentences were built on the same syntactic construction (the test sentences and words are listed in Appendix B):

(1)	Subject	Negation	Verb	Verbal Prefix	Article	Object
	János	*nem*	*véd**te***	***ki***	*az*	*ütést.*
	John	no	parry.PAST.3SG.DEF	PREF	the	blow.ACC
	'John did not parry the blow.'					

The verbs took the PAST.3SG.DEF suffix /tɒ/∼/tɛ/ in every sentence. The verbal prefix [ki] always followed the main verb, therefore all tested vowels were in the environment [t_k]. Every verb stem was monosyllabic and all distinct vowel qualities in Hungarian were used as the stem vowel of a verb in a sentence (the quantity distinction was not taken into account). The neutral /i/ vowel was tested as the stem vowel for two verbs – one taking front suffixes and one taking back ones – to test the effect of different kinds of lexical storage for the two classes argued for by Benus & Gafos (2007). The initial hypotheses of the experiment described below were that centralized vowels would be accepted as vowel reduction is present in Hungarian and that [ə] would be accepted more when it stands for a back vowel than when it stands for a front one ([ɒ] and [ɛ] in the experiment, respectively).

The test sentences were synthesized using the MBROLA text-to-speech system (Dutoit et al. 1996); the first three formants of the vowel in the suffix were deleted and three new formants were filtered therein using Praat, yielding six affix vowel variables: [ɒ], [ɐ], [ə], [ɜ], [ɛ] and [ɪ], with [ɐ] placed halfway between [ɒ] and [ə], [ɜ] placed halfway between [ɛ] and [ə] and the F1 of [ɪ] halfway between [ɛ] and [eː], and

$$F2_{[I]} = \frac{2 * F2_{[E]} + F2_{[e:]}}{3}.$$

The actual formant values of these vowels are given in Table 4. Vowel du-

	[ɒ]	[ɐ]	[ə]	[ɜ]	[ɛ]	[ɪ]
F1	491	453	416	425	435	367
F2	941	1173	1405	1637	1870	1997
F3	2336	2406	2476	2546	2616	2717

Table 4: *First three formants for test affix vowels of the perception study*

ration, pitch and intensity were not altered as the focus of this experiment was the effect of reduction on formants.

Each test sentence listed in Appendix B was altered, with each of the six tested affix vowels edited into the past tense morpheme. Ten stem vowels therefore yielded 60 test sentences, and each speaker was tested three times in three randomized orders to eliminate any artefacts due to the order of the sentences. These 180 sentences were played to the speakers, who had to assign an acceptance score of 1 (worst) to 7 (best) to each sentence they heard.

4.2 Results

The results of this experiment are summarized in Table 5 (N = 45 for front and N = 36 for back vowels in all columns as stems with [i] and back affixes were excluded; t-test was used for significance analysis). The most striking observations that can be made from the study are as follows:

- scores for [ə] were significantly worse for front stems than for back stems with a highly significant difference of means ($t = 12.14$ with d.f. $= 71.52$, $p < 0.001$); the boxplot for this difference is shown in Figure 9;
- there is no significant difference of scores for [ɜ], which is quite on the front half of the vowel chart (F2 = 1637);

AFFIX VOWEL	[ɒ]	[ɐ]	[ə]	[ɜ]	[ɛ]	[ɪ]
FRONT STEM	1.89	2.38	2.73	4.88	6.24	5.98
BACK STEM	6.53	6.64	6.42	5.03	2.39	2.17
p VALUE	<0.001	<0.001	<0.001	0.3881	<0.001	<0.001
SIGNIFICANCE	***	***	***	none	***	***

Table 5: *Mean acceptance scores for a given affix vowel after front and back stems*

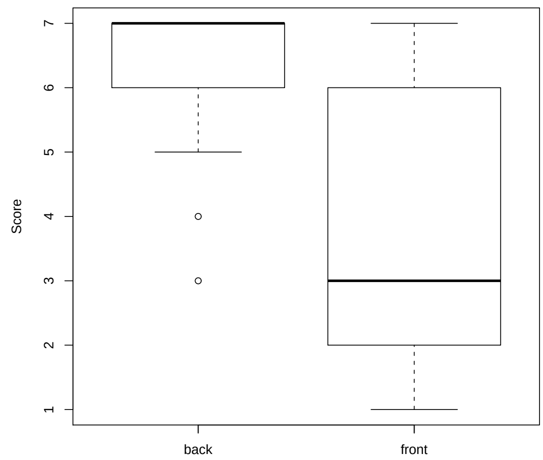

Figure 9: *Acceptance scores for the [ə] vowel in suffixes attached to back and front harmonic stems*

- scores for [ɛ] were non-significantly different from scores for [ɪ] for front stem vowels (t = 1.135 with d.f. = 82.335, p = 0.2596).
- scores for [ɒ], [ɐ] and [ə] were non-significantly different for back stem vowels (p = 0.55 for [ɒ]∼[ɐ], p = 0.27 for [ɐ]∼[ə] and p = 0.61 for [ɒ]∼[ə]);
- stems taking back suffixes with [i] as the stem vowel show significantly better scores than other back stems for an [ɪ] affix vowel ($p \approx 0.01$) and significantly worse scores for an [ɒ] affix vowel($p \approx 0.02$), thus tolerating more front affixes better;
- stems with the front round vowels [y] and [ø] showed a significantly better score for centralized affix vowels than front non-round stems: $p \approx 0.04$ for [ə] and $p \approx 0.01$ for [ɐ].

These observations are in line with the findings of the acoustic experiment: the back vowel phoneme /ɒ/ can be centralized towards [ə] and still be acceptable to listeners, whereas the front /ɛ/ phoneme cannot be centralized, while its raised realization [ɪ] is accepted.

	Target of centralization in						
	Hungarian	Catalan	SLPC	Bulgarian	Belarusian	CI	SI
a	?	ə	ə	ə	a	a	a
ɒ/ɔ	ə	-	o	-	-	o	-
ɛ/æ	e̞/ɪ	ə	e	-	-	e	-
e	?	ə	e	i	a	e	i
o	ə	u	o	u	a	o	u

Table 6: *Hungarian vowel reduction compared to other reduction patterns (SLPC = Sri Lanka Portuguese Creole, CI = Central Italian, SI = Southern Italian)*

5 ANALYSES

5.1 Theoretical relevance of phonetic grounding

As it has been summarized in Section 2.3, theoretical approaches using rich lexicon models and/or diachronic arguments rather than an idealized competence model that excludes 'extra-linguistic' factors rely on detailed phonetic data. Various generative models have been created to describe and predict the existing patterns of phonemic vowel reduction in the languages of the world. If one assumes a non-generative functional approach, these models need to be tested on *subphonemic* processes, like the one seen in Hungarian. A model that is able to describe these processes is favored over those that cannot, as phonological patterns are assumed to emerge from subphonological phenomena.

Table 6 shows that the Hungarian vowel reduction pattern seen above can be easily compared to *phonological* reduction patterns in other languages frequently cited in the literature (Crosswhite 2004; Harris 2005; de Lacy 2006). It is therefore not hard to compare the treatment of these languages in various descriptive models, and to see their predictions for Hungarian.

5.2 Standard OT analysis

The kind of reduction seen in Hungarian is called prominence reduction in Crosswhite (2004), as the main process behind the phenomenon seems to be the reduction of more prominent vowels towards [ə]. The analysis of prominence reduction patterns in Crosswhite (2004) relies on markedness constraints of the form *Unstressed/V which prohibit vowel V in unstressed syllables. These constraints are likely to be universally ranked on a scale that is used to compare more prominent vowels to less prominent ones:

*Unstressed/a ≫ *Unstressed/ɛ,ɔ ≫ *Unstressed/e,o ≫
*Unstressed/i,u ≫ *Unstressed/ə

Faithfulness constraints are then ranked above, below or somewhere between these constraints, and different rankings account for different centralization patterns. For example, the following two faithfulness constrains have to be used to account for the the centralization of /ɛ/ towards [e] (or [ɪ]): Max[+low],[1] which can be demoted in casual speech and Max[+front], which cannot. To illustrate this, the following tableau shows the evaluation of candidates in careful speech where both Max constraints are ranked high (*U/V being an abbreviation for *Unstressed/V):

/ɛ/$_{careful}$	Max[+fr]	Max[+lo]	*U/ɛ,ɔ	*U/e,o	*U/i,u	*U/ə
a. ☞ [ɛ]			*			
b. [e]		*!		*		
c. [ə]	*!	*				*

In casual speech the Max[+low] constraint is ranked lower (anywhere below Unstressed/ɛ,ɔ), thus resulting in prominence reduction:

/ɛ/$_{careful}$	Max[+fr]	*U/ɛ,ɔ	Max[+lo]	*U/e,o	*U/i,u	*U/ə
a. [ɛ]		*!				
b. ☞ [e]			*	*		
c. [ə]	*!		*			*

To account for the behavior of /o/, we need another faithfulness constraint, Max[+back], as [o] and [ə] contrast only in this feature. The demotion of Max[+low] has no effect on /o/, because centralization or raising do not cause a violation of this constraint, as [o] itself is already [−low]. Careful speech evaluation is then as follows:

/o/$_{[+stress]}$	Max[+bk]	*U/ɛ,ɔ	*U/e,o	*U/i,u	*U/ə
a. ☞ [o]			*		
b. [ə]	*!				*

[1] It is assumed that mid vowels are [−high, −low]; if mid vowels were represented as [+high, +low], Max[−high] should be used.

With the faithfulness constraint demoted in casual speech:

$/o/_{[-\text{stress}]}$	*U/ɛ,ɔ	*U/e,o	MAX[+BK]	*U/i,u	*U/ə
a. [o]		*!			
b. ☞ [ə]			*		*

The problem with this analysis is its lack of explanatory power, lack of functional groundedness and *ad hoc* nature. One might point out that both MAX[+BACK] and MAX[+FRONT] have to be used in order to get the Hungarian reduction pattern. The actual position where faithfulness constraints get demoted to seems to be random, and this analysis lacks any type of phonetic or other grounding for this.

The question of graduality is also avoided here: if a certain constraint is demoted to a certain point in casual speech, the quality of the output vowel is set to the target phonetic realization, and we do not observe the gradual and stochastic realization pattern that can be seen in the data. Stochastic OT (Boersma & Hayes 2001) may avoid this problem, but it still does not have the functional grounding that is needed if the approach outlined in Section 2.3 is taken seriously.

5.3 Dispersion Theory analysis

An important phonetic notion when talking about vowel reduction is the dispersion of phonemes in a vowel inventory. Dispersion Theory portraits vowel reduction as the lesser need for dispersion in unstressed environments, that is, the lesser need for a wide space for vowels. Flemming (2004) uses two phonetically grounded constraint types based on this theory: a constraint that enforces maximal dispersion of vowels in the available space (e.g. MINDIST=F1:3, which is violated if two vowels are closer to each other than 3 measurements on an arbitrary scale) and constraints that prefer to minimize articulatory effort (e.g. *SHORT LOW V for F1 centralization or *HIGH EFFORT for F2 centralization). As Dispersion Theory evaluates vowel inventories, it also uses a constraint that maximizes the number of vowel contrasts in a language.

The latter property of this analysis is in fact a disadvantage, as well as the use of auditory effort-based constraints, if the listener (or the learner, the child) is taken to be the source of sound change (Ohala 1981). It is also not clear, whether Hungarian actually supports this theory, as the effect of vowel length, and its retention in the standard spoken dialect is not very well understood yet.

	Free Vs		Vs in words		Vs in context	
Speaker	long	short	long	short	long	short
1	768	583	695	336	428	255
2	859	582	596	372	430	321

Table 7: *Acoustic Systems Contrast measurement of Hungarian vowels in de Graaf (1987)*

De Graaf's (1987) analysis of Hungarian vowel reduction has found reduced dispersion of vowels in context when contrasted to vowels in isolation. He measures an Acoustic Systems Contrast (ASC) variable that is the mean square distance of a given vowel's position from the central vowel's position in the F1-F2 plane. The ASC values in his experiment can be seen in Table 7.

5.4 Dispersion-Focalization Theory

Dispersion-Focalization Theory (DFT, Schwartz et al. 1997) adds a focalization factor to the dispersion-based analyses. Focalization is meant to refer to the observed characteristics of the least 'marked' vowels in spoken languages. The assertion is that the most easily perceived auditory feature of vowels is the convergence of two formants, that is, when they are so close to each other that their energy adds up to one salient frequency peak, which is easily perceived by the human ear and mind. Dispersion and focalization work against each other to some extent, but their balance can explain the distribution of vowel inventory types in the world (cf. Kingston 2007; Becker-Kristal 2007).

Focalization is easy to see on the spectra of the four corner vowels compared to the central non-focalized [ə] vowel as shown in Figure 10. DFT assumes that it is perceptually easy to identify differences in the place of the highest peak in the spectrum, which is the salient convergence of two or three formants (high F1 and F2 for [a], high F2 and F3 for [i], low F0, F1 and F2 for [u]). This is contrasted with the lack of salient convergence, which means a more even spectrum seen for [ə]. The spectrograms of these vowels can be seen in Figure 11.

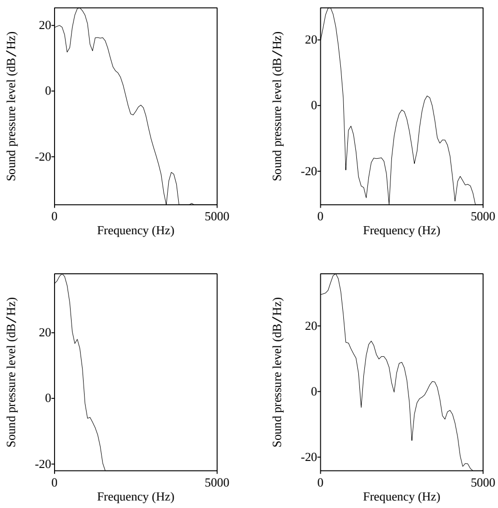

Figure 10: *Spectra of the vowels* [a] *and* [i] *(top row) and* [u] *and* [ə] *(lower row)*

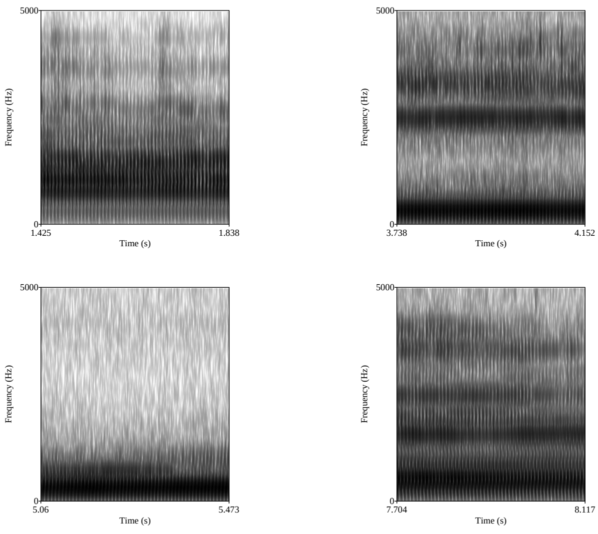

Figure 11: *Spectrograms of the vowels* [a] *and* [i] *(top row) and* [u] *and* [ə] *(lower row)*

		CATALAN V-RED		HUNGARIAN V-RED	
PHON	REPR	QUALITY	REPR	QUALITY	REPR
/a/	(A)	[ə]	()	–	–
/ɒ/∼/ɔ/	(A̲+U)	[u]	(U)	[ə]	()
/o/	(A+U̲)	[u]	(U)	[ə]	()
/ɛ/	(A̲+I)	[ə]	()	[ɪ]	(ə̲+I)
/e/	(A+I̲)	[ə]	()	–	–

Table 8: *Comparison of Catalan and Hungarian vowel reduction in ET-DFT following Harris (2005)*

5.5 Element Theory analysis using DFT

Harris (2005, 2007) uses the phonetic grounding of DFT in his Element Theory (ET) framework for vowels. The abstract elements (A), (I) and (U) used in the phonological representation of vowels therefore have a phonetically grounded meaning, representing the perceptually most salient effects that carry information over the neutral [ə]-like carrier signal:

- (A): called a 'mAss', the salient convergence of high F1 and central F2
- (I): called a 'dIp', the salient convergence of high F2 and F3
- (U): called a 'rUmp', the salient convergence of F0, low F1 and low F2

The representation of corner vowels is the simple element that characterizes them. The central vowel is represented by the lack of any segmental information: /ə/ = (). Non-corner vowels are treated as complex, therefore their representation is a combination of elements; for instance, /o/ = (A+U), /e/ = (A+I). In more detailed systems one element is called the 'head' of the representation having a greater impact on the vowel quality, and the other is a 'dependent'; for instance, /ɔ/ = (A̲+U) and /o̝/ = (A+U̲).

In the ET-DFT framework vowel reduction is easily handled as the loss of some elements, and different reduction patterns are explained as the retention or loss of a particular element. Harris (2005) shows how this works in a variety of languages, including Catalan (see Table 6), which seems to be quite similar to the Hungarian pattern: whereas Hungarian reduces (A) and (U) while keeping (I), Catalan reduces (A) and (I) and retains (U), as it can be seen in Table 8.

The result of the centralization of Hungarian /ɛ/ in this framework would be a segment with an empty head (represented here as (ə̠)) with a dependent (I), which is realized as a lax [ɪ] quality (cf. Harris & Lindsey 1995), the vowel realization seen in the acoustic experiment in Section 3. Catalan /ɔ/ and Hungarian /ɒ/ are represented in the same way as the (non-reduced) realizations of these phonemes are very close to each other and there is no theoretical reason for treating them differentially.

It is important to underline that the use of representations in this model does not mean that these representations would need to have any psychological or cognitive reality. These 'elements' are merely abbreviations for certain phonetic facts as they had been defined in terms of focalization in DFT. The use of these abbreviations in this framework suggests that focalization is a very important perceptual cue, and it points to the importance of the lack of loss of a certain focalized quality: the one represented by the element (I) in the case of Hungarian.

6 CORRELATION WITH VOWEL HARMONY

The Element Theory analysis has the advantage of providing a formal analysis, while having phonetic groundedness. It is capable of making predictions about the behavior of novel vowels and of revealing tendencies or changes that are possible in the vowel inventory of Hungarian. The main prediction is that the palatality distinction is strongly retained in Hungarian, so one would not expect front vowels like /y/ (U+I), /ø/ (A+U+I) or /i/ (I) to centralize their F2 formants; their target of reduction is predicted to be [i] (I) or [ɪ] (ə̠+I). This seems quite odd as the vowel quality of [ø] is the one substituted by Hungarian speakers for a [ə]-like sound (Gósy 1997), therefore its loss of roundedness is a very strong – and falsifiable – prediction of this model.

The fact that the (I) element is intact means that F2 vowel harmony has a strong effect in Hungarian, and can even constrain the reduction of this element. The loss of F2 vowel harmony (this has occurred in Estonian, a genetically related language; cf. Viitso 1998) is, therefore, not likely. Should vowel reduction in unstressed syllables become stronger by time and its effects enter the phonological domain, at least two reduced phonemes (back [ə] and front [ɪ]) are predicted to survive, whose distribution could still be governed by vowel harmony, if such bold predictions can be made by the models used above.

The question can be raised why vowel harmony is so resistant that the (I) element is preserved in Hungarian vowel reduction. Vowel harmony could even possibly strengthen reduction, as the information about the frontness of the word can also be carried by only one syllable, the first one with the primary stress. On the other hand, in a language with vowel harmony the persistence of a certain 'feature' or articulatory (and therefore auditory) cue might be easier or more straightforward.

Recent studies and the present experiment provide evidence for the latter point of view. Pearce (2009) has shown that vowel harmony has an effect on subphonemic vowel reduction: it conserves the harmonizing feature. She also shows some results on Hungarian, where she finds quite similar effects to those in the experiment above: back vowels centralize while front vowels do not. She has found this pattern in other F2-based vowel harmony systems (even in genetically related languages such as Finnish) as well as for other auditory cues, like [±ATR].

7 FURTHER RESEARCH

As it seems that the preservation of the (I) element in reduction is related to the vowel harmony found in the language, further research has to be carried out on the acoustic behavior of other vowels in Hungarian, with hypotheses running along the predictions of the ET-DFT model. This means that distinctions in F2 are expected to be retained, with centralization for back vowels and no change or laxing for front vowels. The problem of the differential behavior of front vowels in Hungarian vowel harmony should also be investigated in more detail, as it is possible that effects such as the Height Effect and the Count Effect described in recent works on Hungarian vowel harmony (see Hayes & Londe 2006 and Hayes et al. 2009) can influence the degree of reduction of the (I) element.

The retention of the (U) element in front rounded vowels is also possible as this group of vowels behaves quite differently from the front unrounded group (called 'neutral' in the literature) in determining the harmonical class a stem belongs to. Further auditory and perceptual analysis of the quality of vowels in stems with /i/, /iː/ and /eː/ that have back suffixes attached to them should also be carried out, to test Benus & Gafos's (2007) claim that the articulatory properties of these vowels differ from those within a stem that prescribes front suffixes (e.g. /hiːvok/ 'I call' and /hiːvɛk/ 'believers' from the stems /hiːv$_{[+\text{back}]}$-/ 'call' and /hi-$_{[-\text{back}]}$/ 'believe').

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APPENDIX A: TEST SENTENCES FOR THE ACOUSTIC EXPERIMENT

Casual readings:

Sehol sem találok egy tiszta poharat. (-)
Nem látok esélyt arra, **hogy** megváltozna. (o0)
Ez a gyerek i**s ak**ar játszani vele. (a1)
A miniszterelnök végre **kegy**et gyakorolt. (e1)
Azt mondta, hogy de**hogy**isnem, ő ott volt. (o2)
Nem is tudom, hova menjek bevásárolni. (-)
A gyereke**k egy** új világban élnek. (e0)
Tegnap a csapat elnö**ke gy**akorolt a stadionban. (e2)
Jópofa állat a **taz**mán ördög. (z1)
Minden nap a **hogy**létéről érdeklődött. (o1)
Ügyesen készíte**tt az** este valamit. (z0)
Ez az ország mente**s a k**orrupciótól. (a0)
Nem mindig lá**tta Z**olit a játék közben. (z2)
Látod, ők nem olyan oko**sak**, mint hiszik. (a2)

Careful readings (words):

sakk (ag), TAZ (zg), kegy (eg), hogy (og), lét (ég), sír (íg), kűr (űg), tó (óg), nyár (ág), búr (úg)

APPENDIX B: TEST SENTENCES FOR THE PERCEPTIONAL EXPERIMENT

Mari nem vette ki a pénzét.
János nem védte ki az ütést.
Lajos nem vitte ki a szemetet.
Gábor nem itta ki a poharát.
Az igazgató nem vágta ki a diákot.
Ági nem rakta ki a díszeket.
Bea nem dobta ki az emlékeit.
Sanyi nem rúgta ki a beosztottját.
Réka nem küldte ki a postást.
Ádám nem lökte ki a virágot.