AN ACOUSTIC STUDY OF UNDERSPECIFIED VOWELS IN TURKISH

By

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Abstract

This paper examines the acoustics of underspecification and vowel harmony (VH) in Turkish. In Turkish, vowels in suffixes that change according to VH rules are widely believed to be underspecified for rounding and/or backness. Underspecification has previously been thought to persist in the acoustic realization of underspecified segments. In the present study, it was hypothesized that underspecification in Turkish vowels persists in their acoustic realization even after specification due to incomplete specification and that harmonizing vowels assimilate to particular vowel categories rather than the trigger vowels themselves. An experiment was run comparing underspecified suffix vowels to their specified counterparts in roots. Of the vowels underspecified for rounding, unrounded high vowels had a significantly higher F2 and [i] had a significantly lower F2 compared to their specified counterparts at all three points of measurement. This could be a case of enhancement, where the features of the first vowel are copied and enhanced to optimize perception. No such differences were found for vowels underspecified for backness. Additional effects of specification were found to be significant in individual specified/underspecified vowel pairs in terms of F2. A second experiment was run to determine if VH is a coarticulatory process in which the harmonizing vowel assimilates to the trigger vowel itself. Of the high underspecified suffix vowels, [u] was found to differ significantly according to the height of the preceding vowel, while low suffix vowels differed significantly according to the rounding of the preceding vowel. The results of the second experiment showed that coarticulation is an active process in Turkish which affects underspecified vowels as well. It was concluded that coarticulation and specification are two separate processes. Specification is a process uniform throughout the vowel, starting from a

position neutral to the underspecified features and eventually overshooting them, while coarticulation is a dynamic process, affecting the area closest to the trigger vowel.

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1. Introduction

1.1. Vowel Harmony

Vowel harmony (VH) can be described as a process in which one or more features spread between vowels within a specific domain (Gordon 2006: 418). Another way in which VH may be viewed is as a phonological constraint according to which vowels within a specific domain, be it phonological or morphological, must agree in terms of one or more features (Baković 2000: 1). Baković notes, however, that exceptionless VH systems are rare and he attempts to capture such exceptions through the interaction of agreement, faithfulness and markedness constraints using Optimality Theory.

A number of types of VH have been documented in the languages of the world. Height harmony is common in Bantu languages. In Swahili, for example, a suffix may have two variants, one with *i*/*u* following a root in *i*, *u*, or *a*, and another variant with *e*/*o* following roots in *e* or *o*: *pit–i–a* 'pass by', *pand–i–a* 'climb onto', and *shuk–i–a* 'come down to' compared to *tok–e–a* 'come from' and *end–e–a* 'go towards' (Ohala 1994: 492; Wald 2009: 890).

ATR harmony is found in a number of languages in East and West Africa which contain pairs of vowels in their inventory contrasting the feature [ATR], i.e. advanced versus retracted tongue root (Ohala 1994: 492). Akan, for example, has nine vowels, four of which are [+ATR] (/i u e o/) and four [–ATR] (/ɩ ʊ ɛ ɔ/), while the low vowel /a/ is phonetically [–ATR] lacking a [+ATR] counterpart. Due to ATR harmony, all vowels in a word must agree with respect to the feature [ATR], except for /a/, which may occur in either type of root: [+ATR] *àsí* 'adversary' and *òsé* 'a yell' versus [–ATR] *àsí* 'father' and *sέsɛ* 'shrimp' (Hess 1992: 476–7; 481).

Both palatal and rounding harmony, according to which vowels in a specific domain must agree in backness and rounding respectively, are common among the Uralic and Altaic languages

(Ohala 1994: 492). Hungarian, for example, exhibits both types of harmony in certain suffixes that have three variants: ACC = *ɛt* after front unrounded vowels (*hɛrɛg–ɛt* ‘duke+ACC’), *øt* after front rounded vowels (*økr–øt* ‘ox–ACC’), and *ot* after back vowels (*lakat–ot* ‘(pad)lock+ACC’) (Abondolo 2009:485).

Two other types of VH attested are nasal and pharyngeal harmony. Ohala treats these are distinct from the other types of VH in that they are triggered by consonants rather than vowels, even though a feature may then spread between vowels (1994: 493).

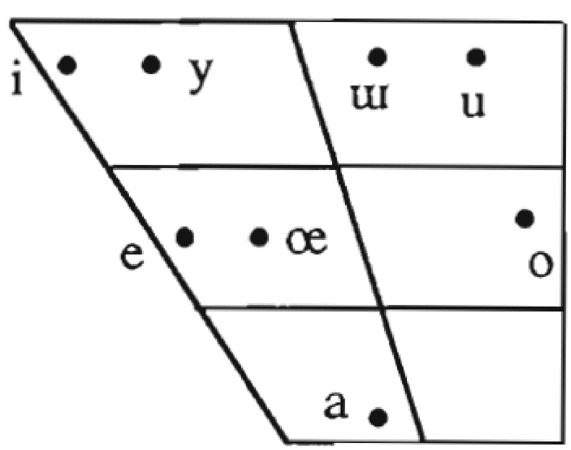
1.2. Vowel harmony in Turkish

Standard Turkish contains a symmetrical system of eight vowel phonemes contrasting backness, height, and rounding. They are shown in terms of their features in Table 1 and in the vowel space in Figure 1.

Table 1: The Vowels of Turkish in IPA

	Front		Back	
	Unrounded	Rounded	Unrounded	Rounded
High	i	y	ɯ	u
Low	e	ø	ɑ	o

Figure 1: Turkish Vowel Chart (taken from Zimmer & Orgun 1999: 155)



Vowels in loanwords may be phonemically long, while in native words length is only due to compensatory lengthening and so is not phonemic (Kornfılt 1997: 489). There are, however, few minimal pairs distinguished by length alone, e.g. *dün* [dyn] ‘yesterday’; *düğün* [dy:n] ‘wedding’.

Words in Turkish generally conform to VH. In Turkish the domain of VH is the phonological word, which is comprised of a root and all suffixes attached to it, which may be numerous because Turkish is an agglutinative language (Kornfılt 2009: 527). The direction in which it applies is left to right, i.e. a vowel must agree with a vowel in an immediately preceding syllable. A compound comprises two domains. No alternation occurs in roots, while suffixes alternate according to the features of the final root vowel. Clements & Sezer (1982) classify this type of patterning as symmetrical, as opposed to an asymmetrical patterning, in which both roots and affixes alternate according to some dominant, non–alternating morpheme, such as is found in Somali. Baković classifies Turkish VH as a stem–controlled system, in which a vowel in more peripheral morphemes are controlled or dependent upon those in less peripheral segments, explaining them by the use of stem–affixed form faithfulness constraints (2000: 66–68).

Two types of VH are present in Turkish, palatal and rounding harmony. Palatal harmony dictates that vowels in adjacent syllables must agree with respect to the feature [back]:

[kɯrmɯzɯ]	‘red’	[ev–de]	‘house–LOC’
[sor–mɑk]	‘ask–INF’	[yzym]	‘grape’
[bɑbɑ–m]	‘father–1.SG.POSS’	[gemi–ji]	‘ship–ACC’

According to rounding harmony, vowels in adjacent syllables must agree with respect to the feature [round]. However, while palatal harmony applies to all vowels, rounding harmony applies only to high vowels (/i y ɯ u/):

[gøz–ym]	‘eye–1.SG.POSS’	[bulut–lu]	‘cloud–y’
[sen–i]	‘you–ACC’	[mɑsɑ–nɯn]	‘table–GEN’
[diz–i]	‘knee–ACC’	[kol–u]	‘arm–ACC’

The asymmetry between the vowels to which palatal and rounding harmony apply means that rounded low vowels (/ø o/) do not occur in non–initial syllables in harmonic roots or in suffixes: [gøz–de] ‘eye–LOC’, not *[gøz–dø]. In turn, if a suffix with a low vowel precedes another with a high vowel then the suffix with the high vowel may not contain a rounded vowel:

[gøz–y] ‘eye–ACC’, but [gøz–ler–im] ‘eye–PL–1.SG.POSS’.

This means that high vowels are subject to both palatal and rounding harmony, also called four–way harmony because all four (/i y ɯ u/) alternate with each other. The low, unrounded vowels (/e ɑ/) harmonize only with respect to backness, called two–way vowel harmony.

While these patterns of harmony are completely regular in most native roots and the majority of suffixes, there are nonetheless numerous roots and several suffixes that are either completely disharmonic or only partially so. Due to centuries of contact with Arabic and Persian, as well as more recent contact with European languages, the Turkish lexicon possesses hundreds of disharmonic roots:

[mysɑːde] ‘permission’	[kitɑp] ‘book’	[kɑlem] ‘pencil’
[kytypɑːne] ‘library’	[meny] ‘menu’	[televizjon] ‘TV’

Additionally, some loanwords take disharmonic suffixes because of suffixes that they took in the language they were borrowed from:

[sɑːt–i] ‘hour/clock–ACC’	[hɑrb–i] ‘war–ACC’	[kɑlp–i] ‘heart–ACC’

Lees notes that these are most often due to the fact that in Arabic they ended in a non–emphatic rather than velarized emphatic consonant and that children and illiterate adults will apply harmony rules as expected (1961: 57). Lastly, there are borrowed and native suffixes which are either completely or partially invariable:

[–izm]:	[komynizm]	'communism'
[–(I)jor–]:	[gør–yjor–um]	'see–PRES.PROG–1.PERS.SG'
[–ki]:	[ɑmɑrikɑ–dɑ–ki]	'America–LOC–NOMINAL.'

Whether or not vowel harmony is an active process in Turkish roots is controversial. As mentioned earlier, no alternation occurs in roots. Clements and Sezer (1982) have shown that, apart from the lack of alternation, there is an abundance of disharmonic loanwords which are, whether loanwords or not, exceptional only in their disharmony and so may not be assumed to be marked as [–native], as had been previously proposed. Likewise, they argue that if VH were an active, productive process in roots, then loanwords would undergo harmonization. For these reasons, we will follow Clements and Sezer (1982), Polgádi (1999) and others and assume that VH is not productive in roots.

1.3. Underspecification

The term underspecification is used in phonology to refer to cases in which a segment lacks one or more features underlyingly, but seems to possess them in the surface realization. In terms of phonetics, underspecification may be thought of as a lack of a specific target associated with a phonological feature (Inkelas 2006: 224–5).

Two main arguments have been put forward as evidence for underspecification: arguments out of variability and those out of transparency (Keating 1988: 275). According to variability arguments, if a segment is variable with respect to a particular feature and its variability is completely dependent on one or more segments other than itself, it may be said to be underspecified for that feature in its underlying representation. The second type of argument stems from the way in which a segment may act with respect to neighboring segments. If a segment has no effect on a process such as vowel harmony, for example, the segment is essentially transparent to the process and so to the features of its neighbors that it allows to harmonize. It may be said then that it is underspecified for that particular feature.

Comparatively little research has looked at how underspecification may be realized phonetically and how it may be quantitatively studied. Keating (1988) proposed that underspecification may persist in the acoustic signal, for example, due to incomplete specification and offers specific ways in which underspecification may be studied in the acoustic signal. With respect to transparency, she specifies two ways in which it can be quantitatively studied. First, an underspecified segment exhibiting transparency should contribute nothing of its own to the relevant signal corresponding to the feature. For example, if a consonant is underspecified for backness, F2 throughout a VCV sequence should vary completely according to the F2 of the adjacent vowels. Thus, one would expect a clean transition from vowel to vowel with no steady state corresponding to the backness of the consonant. In the same way, if a segment is transparent, it should allow interaction between segments which are adjacent to it, such as vowel harmony between VCV, without affecting this interaction, namely, by contributing anything of its own to the process for which it is transparent.

Of the studies that have examined underspecification phonetically, most have looked at consonants or to what extent transparent segments are really unaffected by adjacent processes such as vowel harmony. For example, Gordon (1999) examined the vowels in Finnish which have been termed neutral vowels because they do not take part in VH and act transparently, allowing the interaction of adjacent segments. In native Finnish words, all vowels within the domain of the word must agree in backness, with the exception of the two neutral vowels, /i/ and /e/, which may occur in either front or back stems. Using a word list containing each of the neutral vowels in each possible environment with regard to backness, i.e. preceding, following and between back and front vowels, Gordon recorded and examined the vowels acoustically. He found that, while F1 did not vary significantly as a function of the vowel environment, F2 did vary significantly. Specifically, F2 values for neutral vowels were significantly lower following back vowels compared to those following front vowels. Thus, when neutral vowels follow back vowels, despite being phonetically front and supposedly invariable and transparent, they are significantly backed. Gordon's findings mimic the phonological properties of VH in Finnish. Namely, backness and not height spreads progressively rather than regressively.

Another work which looked at transparent vowel is Beňuš (2005), which examines the transparent vowels /i /, /í/, and /é/in Hungarian. Using magnetometry (EMMA) and Ultrasound techniques, he looked at them in both front and back environments and found that in a front environment, i.e. a front harmony context, they were less retracted compared to when they were in a back environment.

Another study looking at underspecification in vowels is Choi (1995), which examined whether underspecification persists in the phonetic realization of vowels in an Austronesian language, Marshallese. In Marshallese, medial short vowels vary with respect to backness according to the consonantal environment in which they occur. Namely, between palatalized consonants front vowels occur, between velarized consonants unrounded back vowels occur, and between rounded consonants rounded back vowels occur. When the consonantal environment is not uniform, e.g. the preceding consonant is palatalized and the following one is rounded, the vowel has a phonetic quality intermediate between those that would occur in symmetrical contexts. Taking these vowels to be underspecified for backness, Choi hypothesized that this underspecification persisted in the phonetic realization of the vowels. When both consonants in the sequence CVC have the same secondary articulation, there should be a smooth transition of F2 between consonants. When they are not, there should be no steady state corresponding to the F2 contributed by the vowel. This means that the vowel in a CVC sequence does not have its own trajectory and value; rather it is entirely a function of the adjacent consonants. The results showed that while variation of F2 in the vowel as a function of the surrounding consonants' F2 was significant, so was the variation as a function of vowel category, though to a lesser extent. Likewise, the expected formant patterns (robust consonant–to–consonant articulations) were found. This suggests that underspecification does indeed persist in the phonetic signal, but that vowel category of the surface realization nonetheless does play a role.

Hess (1992) acoustically examined ATR harmony in Akan, one of the languages of Ghana. In Akan, with the exception of one vowel, the low vowel /a/, all vowels within the domain of the word generally must agree with respect to the feature [ATR], which is contrastive for the mid and high vowels: [+ATR] /i e o u/ and [–ATR] /ɩ ɛ ɔ ʊ/. For example, /kòfí/ '*a boy's name*' contains two [+ATR] vowels, while /tɕɩ́rɛ́/ '*show'* contains two [–ATR] vowels (476–7). Prefixes agree in terms of [ATR] with the vowel in the stem–initial syllable. /a/ is considered phonetically [–ATR] but does have a raised allophone [æ] occurring before high [+ATR] vowels (/i u/), which has a disputed status with respect to its categorization as [+ATR] or [–ATR].

In her study, Hess attempted to reconcile two competing accounts of the phonetics of ATR harmony in Akan. According to Clements (1981), rather than only in the case of /a/, there is a general assimilatory process according to which [–ATR] vowels are raised when preceding a word, whether in a compound or sentence, whose initial syllable contains a high [+ATR] vowel

(/i u/). Through this process, [–ATR] /ɪ ʊ/ are raised to an identical position as [+ATR] /i u/, while the mid [–ATR] vowels /ɛ ɔ/ are raised to an intermediate position between /ɛ ɔ/ and the [+ATR] vowels /e o/. Additionally, this process is not restricted to immediately preceding syllables; rather it extends gradually over several preceding syllables. This account contrasts that by Dolphyne (1988: 23, cited in Hess 1992), according to which this assimilatory process is not a gradual, phonetic process but rather is a categorical, phonological process limited to the syllable immediately preceding the morpheme with a high [+ATR] vowel (/i u/). For example, [–ATR] /ɛ/ in *asɛm* becomes [+ATR] [e] in the compound *asenhunu* 'useless talk'. Thus, as Hess sees it, the crucial distinction between the two accounts is that for Clements, tongue height changes and not tongue root and larynx position, whereas for Dolphyne the crucial change is that of tongue height and larynx position.

Hess began by determining which acoustic measurements most reliably distinguished [+ATR] vowels from [–ATR] vowels. Of the four measurements examined (frequency and bandwidth of formants, vowel duration, and the relative amplitudes of spectral components), she found that the frequency and bandwidth of F1 best distinguished the two vowel series, with F1 bandwidth being the more reliable of the two measurements.

Next, Hess used F1 frequency and bandwidth to attempt to answer three questions: 1) Does the form of ATR harmony discussed above involve a partial assimilation of tongue height (per Clements), or a complete change in the value of the feature [ATR] for the assimilating vowel? 2) Is assimilation limited to the immediately preceding syllable, or does it affect vowels throughout the word? 3) If it does extend throughout the word, is it uniform throughout, regardless of proximity to the trigger vowel? (Ibid. 487).

In order to address questions 2 and 3, six sentences were used containing the word /àdáká/ '*box'* immediately followed by a syllable containing a [+high, +ATR] vowel or /a/, which was the control context. A consistent effect of a lowering of F1 and a rising of F2 and F3 was found only for /a/ in the final syllable of /àdáká/ when followed by a [+high, +ATR] vowel, contrary to the Clements' claim that assimilation extends over the entire word.

To determine whether the assimilation discussed is partial and involves tongue height, as Clements claimed, or complete and involves the feature [ATR], as Dolphyne claimed, Hess tested the [—ATR] vowel /ɛ/ in six sentences, as before, in which the word /asɛ́/ '*beans*' is followed by either a [+high, +ATR] vowel or /a/, which is the control context. The frequency of F1 was lowered before a [+high, +ATR] vowel (/i u/) but to in between that of /ɩ/ ([—ATR]) and /e/ ([+ATR]). The bandwidth of F1 for /ɛ/, however, was comparable to that of /e/ when followed by /i u/ and comparable to that of /ɩ/ ([—ATR]). These results lend support to Dolphyne's claim that assimilation of a [—ATR] vowel to a [+ATR] vowel in the initial syllable of a following morpheme involves the complete assimilation of the [ATR], which Hess has found to correlate most strongly with F1 bandwidth.

Mention should also be made of the similarity of studies on the acoustics of underspecification and studies looking at the acoustics of incomplete neutralization, the most famous case being that of final obstruent devoicing. A number of studies have found significant acoustic differences between underlyingly voiced and voiceless obstruents even after final devoicing (e.g. for German: Port & O'Dell 1985; for Russian: Pye 1986). We may view the difference between incomplete neutralization and incomplete specification as one of direction. In the case of incomplete neutralization, an underlying contrast is neutralized and so we are starting with underlyingly specified features. In the case of incomplete specification, however, we are starting with underlyingly underspecified features which will obtain values for those features through specification. While it is possible to view VH in Turkish as a case of neutralization for specific features (rounding and/or backness) in a specific domain, the domain would have to be individual morphemes, which seems to overcomplicate the situation. More importantly, the focus of this study is on the process of VH as a process of specification and not on the starting point where feature contrasts could be seen as neutralized. Similar to studies on incomplete neutralization, as will become apparent in the next section, we expect the process of specification through VH in Turkish to be an incomplete process and to find acoustic differences between segments which are seemingly identical in their surface realizations.

2. Current Study

2.1. Goals and Expectations

The main goal of the present study is to examine the possibility that underspecification persists in the acoustic realization of Turkish suffix vowels. In the process, we hope to answer a number of fundamental questions concerning the nature of VH in Turkish and how specification takes place. First, we hope to answer whether the underlyingly specified and underspecified vowels differ acoustically and so whether specification is partial or complete. Just as neutralization of features in a particular context have often been found to be incomplete, here also we think it reasonable to expect that the process of specification may also be incomplete and so leave quantitative residue, so to speak. In addition, we hope to answer two further questions, namely, whether specification is a dynamic or uniform process throughout the target vowel and whether it is assimilatory or categorical[1] in nature. By assimilatory is meant that the change is one of gradual assimilation to the target, in contrast to a categorical change in which the target vowel changes to approach a particular fully specified vowel category which is determined by the trigger vowel. These three properties of specification due to VH and their predicted possible outcomes are listed in Table 2.

[1] It is important to note that the term 'categorical' is not used in the sense it which it is most used in phonological literature, to refer to a complete, non–gradual change.

Table 2: Predicted possible properties of specification.

Specification		Uniformity		Mode of Change	
Partial	Complete	Dynamic	Uniform	Assimilatory	Categorical
The surface forms of underspecified vowels do not equate those of specified vowels.	The surface forms of underspecified vowels are identical to those of specified vowels.	Specification does not reach the same conclusion throughout the entirety of the vowel.	Specification is a uniform process with identical results throughout the entirety of the vowel.	Specification is an assimilatory, gradual process; target vowels approximate the trigger vowels acoustically.	Specification is a categorical process in which the target vowels approximate fully specified vowels, whose features are determined by trigger vowels.

Concerning these three features, we hypothesize that specification due to VH in Turkish is partial, dynamic, and categorical. These properties characterize a process in which a trigger vowel determines the category of vowel which may follow. This vowel category refers to a specific fully specified vowel. The features of the vowel category for which the target vowel is underspecified act as phonetic targets for the target vowel. Through specification, the target vowel moves towards those targets associated with the fully specified vowel but ultimately undershoots them. The process is dynamic in that the target vowel approaches the phonetic target values associated with the specified vowels least closely at the onset and most closely at the offset, as specification reaches its end. Thus, what we expect to find is that underspecified vowels undershoot the phonetic target values of fully specified vowels associated with the features for which they are underspecified. They differ most from their target values at the onset. Proximity to the trigger vowel actually, then, means greater distance from the absolute target associated with the specified vowel.

As discussed earlier, most suffix vowels in Turkish alternate predictably according to the final vowel of the root to which they are attached. Because they alternate entirely according to the vowel features of the final root vowel, the alternating suffix vowels may be assumed to be underspecified for the features which alternate, which are in the case of Turkish suffixes backness and rounding. Because underspecified vowels in Turkish lack specification for the features [back] and/or [round], the main acoustic correlates for which they are expected to be underspecified are F2 and F3. Backness is correlated with a lowering of F2, while rounding causes a lowering of F2 and F3 as well as a lowering of F1 in low vowels (Stevens 1998: 283, 291–3). Through specification the trigger vowel will determine the vowel category whose values of F2 and F3 or F3 alone will become the target values for the originally underspecified vowel. Table 3 below illustrates this process.

Table 3: The hypothesized process of specification.

<table>
<tr><th colspan="2">Target Vowel</th><th colspan="2">Trigger Vowel</th><th rowspan="2">Specification of Backness</th><th rowspan="2">Target Vowel Category</th></tr>
<tr><th>[high]</th><th>[round]</th><th>[back]</th><th>[round]</th></tr>
<tr><td rowspan="4">+</td><td rowspan="4">0</td><td>—</td><td>+</td><td rowspan="4">F2/F3 ⟶</td><td>[y]</td></tr>
<tr><td>—</td><td>—</td><td>[i]</td></tr>
<tr><td>+</td><td>+</td><td>[u]</td></tr>
<tr><td>+</td><td>—</td><td>[ɯ]</td></tr>
<tr><td rowspan="2">—</td><td rowspan="2">—</td><td>—</td><td>N/A</td><td rowspan="2">F2 ⟶</td><td>[e]</td></tr>
<tr><td>+</td><td>N/A</td><td>[ɑ]</td></tr>
</table>

We stated earlier that due to partial, incomplete specification, the values associated with the underspecified features, F2 and F3, are hypothesized to undershoot those associated with the fully specified vowel category which is its target. Concerning the direction and point of origin from which the underspecified vowel starts, it is assumed that underspecified vowels start from a neutral position with respect to the features for which they are underspecified and so also in terms of their associated phonetic correlates, i.e. F2 and F3. Thus, undershoot here is used to mean that the underspecified vowel will not fully reach the value associated with the specified vowel, starting from a neutral position. It does not mean that the value of the underspecified vowel will necessarily be lower than that of the specified vowel.

Underspecified high vowels, then, are hypothesized to start from a neutral position with respect to backness and rounding and never fully reach the target values associated with fully specified vowels. For example, underspecified [i] is predicted to be less front (lower F2) and more rounded, i.e. less spread (lower F2 and F3) than its specified counterpart. Whereas underspecified high vowels lack specification for both backness and rounding, their low counter parts are only underspecified for backness and so F2 alone is predicted to undershoot the values associated with the specified low vowels. As there is no height harmony in Turkish and so no underspecification for the feature [high], no differences in the values of F1 between underspecified and specified vowels are predicted for either the low or the high vowels. Specific predictions regarding the effects of underspecification for each feature are illustrated below in Table 4.

Table 4: Predicted effects of underspecification by feature

	Backness		Rounding	
Vowel	[back]	Effect of incomplete specification	[round]	Effect of incomplete specification
[i]	–	lower F2	–	lower F2 and F3
[y]	–	lower F2	+	higher F2 and F3
[ɯ]	+	higher F2	–	lower F2 and F3
[u]	+	higher F2	+	higher F2 and F3
[ɑ]	+	higher F2		
[e]	–	lower F2		

It will be noticed that in the case of [y] and [ɯ] there is a contradiction in the direction of the effects of underspecification on F2. [y] is a front rounded vowel and so is expected to have a lower F2 value due to underspecification for backness but a higher F2 due to underspecification for rounding. Exactly the opposite is true for [ɯ]. While both backness and rounding affect F2, it is predicted that the greatest effect upon F2 will be due to backness. As Turkish has a symmetrical vowel system in which each vowel has a rounded counterpart, it is possible that F3 may be the principal distinguishing acoustic correlate of rounding. Thus, underspecified [y] will have a lower F2 value but higher F3 value than specified [y], even though the effect of lowering of F2 may not be as strong as in the case of [i] due to the effect from underspecification for rounding.

In order to understand the predicted outcome of these effects on the values of F2 and F3, it will be helpful to look at previous findings of studies examining the acoustic properties of vowels in Turkish. Oytun et al (2004) examined the properties of vowels in Turkish both in isolation and in words and sentences as pronounced by adult males, adult females, male children, and female children. The mean values for adult males of F2 and F3 for vowels in isolation as well as in sentences and words are listed below in Table 5 in ascending order.

Table 5: Mean values of F2 and F3 for male adults reported by Oytun et al (2004).

Isolation				Sentence/Words				
F2		F3		F2		F3		
909 Hz	[u]	2369 Hz	[y]	955 Hz	[u]	2369 Hz	[y]	Low
1064 Hz	[o]	2401 Hz	[u]	1064 Hz	[o]	2420 Hz	[u]	
1259 Hz	[ɑ]	2549 Hz	[ø]	1382 Hz	[ɑ]	2558 Hz	[ø]	
1517 Hz	[ø]	2614 Hz	[e]	1526 Hz	[ø]	2614 Hz	[e]	
1578 Hz	[ɯ]	2695 Hz	[o]	1578 Hz	[ɯ]	2690 Hz	[ɑ]	
1633 Hz	[y]	2706 Hz	[ɑ]	1633 Hz	[y]	2695 Hz	[o]	
1834 Hz	[e]	2722 Hz	[ɯ]	1834 Hz	[e]	2722 Hz	[ɯ]	
2178 Hz	[i]	2943 Hz	[i]	2079 Hz	[i]	2879 Hz	[i]	High

The order is nearly the same in isolation as in sentences and words, except that [ɑ] has a slightly higher F3 than [o] in isolation while the opposite is true in sentences and words. As underspecification affects high vowels and low vowels differently, it will be best to consider them separately. Leaving aside [o] and [ø], the following hierarchies emerge with respect to F2 and F3 based on Oytun et al.’s findings:

Table 6: Vowel hierarchies of mean values of F2 and F3 reported by Oytun et al (2004).

	F2	F3
High Vowels	[u] [ɯ] [y] [i]	[y] [u] [ɯ] [i]
	Low → High	Low → High
Low Vowels	[ɑ] [e]	[e] [ɑ]

Based upon the hierarchies in Table 6, we predict the following:

- *Prediction 1a*: Underspecified front vowels ([i], [y], [e]) will have lower F2 values compared to their fully specified counterparts.
- *Prediction 1b*: Underspecified back vowels ([ɯ], [ɑ], [u]) will have higher F2 values compared to their fully specified counterparts.
- *Prediction 1c*: Underspecified high rounded vowels ([y], [u]) will have higher F3 values compared to their fully specified counterparts.
- *Prediction 1d*: Underspecified high unrounded vowels ([i], [ɯ]) will have lower F3 values compared to their fully specified counterparts.
- *Prediction 1e*: No differences will be found for values of F1 between underspecified and specified vowels.

Table 7: Summary of predicted directions of effects of underspecification upon F2 and F3.

	F2	F3
High Vowels	[u] [ɯ] [y] [i]	[y] [u] [ɯ] [i]
	Low → ← High	Low → ← High
Low Vowels	[ɑ] [e]	

In order to lend further support to our hypothesis that specification in Turkish due to VH is a partial, dynamic and categorical process, a second possibility will be examined. Namely, that it is a partial, dynamic and assimilatory or coarticulatory process. In this case, the values of the target vowels associated with the underspecified features move towards those of the trigger vowel itself, rather than a particular category of specified vowel determined by the trigger vowel. Specification is still hypothesized to be incomplete and dynamic, i.e., the values of the target vowel associated with the underspecified features are still predicted to undershoot the values that they move towards, but in this case those values are of the trigger vowel. In distinction to the first hypothesis, here we would expect the target vowel to most closely approximate the values associated with the target features in the trigger vowel at the onset rather that at the offset.

In this view, the values of F2 in low target vowels and F2 and F3 in high target vowel vary according to those of the trigger vowel. As each target vowel may follow more than one trigger vowel, a difference in F3 and/or F2 is predicted in the target vowel when preceded by distinct trigger vowels. In order to understand the predicted direction for each vowel according to its trigger vowels, first a complete hierarchy of F2 and F3 values is shown below in Table 8.

Table 8: Complete vowel hierarchies of mean values of F2 and F3 in isolated vowels reported by Oytun et al (2004).

	F2	F3
High Vowels	[u] [ɯ] [y] [i]	[y] [u] [ɯ] [i]
	Low → High	Low → High
Low Vowels	[o][ɑ][ø] [e]	[ø][e][o] [ɑ]

Because the process of specification is, in this view, an assimilatory process, we expect that a target vowel will assimilate towards the values of the trigger vowel for which it is underspecified, i.e. F2 and F3 for high target vowels and F2 alone for low target vowels. In this way, if a target vowel may be preceded by two trigger vowels, one of which has a lower F2 value than the other, the target vowel is also expected to have a lower F2 value before the trigger vowel with a lower F2 value. Given the hierarchies in Table 8, it is predicted that:

- *Prediction 2a*: For [i], [ɯ] and [y], F2 will be lower when the trigger vowel is low compared to when it is a high vowel.
- *Prediction 2b*: For [u], F2 will be lower when the trigger vowel is high ([u]) compared to when it is a low vowel ([o]).
- *Prediction 2c*: For the low vowels ([e] and [ɑ]), F2 will be lower when the trigger vowel is a rounded vowel compared to when it is an unrounded vowel.
- *Prediction 2d*: For high unrounded vowels, F3 will be lower when the trigger vowel is a low vowel.
- *Prediction 2e*: For high rounded vowels, F3 will be lower when the trigger vowel is a high vowel.
- *Prediction 2f*: No effect of the trigger vowel will be found upon F3 for the low vowels or upon F1 for any vowel.

These predictions are further illustrated below in Table 9.

Table 9: Predicted effects of the trigger vowel upon the target vowel.

<table>
<tr><th>Target Vowel</th><th>Trigger Vowels</th><th>Effect on F2</th><th>Effect on F3</th></tr>
<tr><td>[i]</td><td>[i], [e]</td><td rowspan="3">Lower when trigger vowel is low</td><td rowspan="2">Lower following low vowels.</td></tr>
<tr><td>[ɯ]</td><td>[ɯ], [ɑ]</td></tr>
<tr><td>[y]</td><td>[y], [ø]</td><td rowspan="2">Lower following high vowels.</td></tr>
<tr><td>[u]</td><td>[u], [o]</td><td>Lower when trigger vowel is high</td></tr>
<tr><td>[e]</td><td>[i], [y], [e], [ø]</td><td rowspan="2">Lower following rounded vowels.</td><td rowspan="2">None.</td></tr>
<tr><td>[ɑ]</td><td>[ɯ], [u], [ɑ], [o]</td></tr>
</table>

2.2. Methods

2.2.1. Participants

A total of 6 participants took part in this study, consisting of 1 female and 5 males. All participants signed a statement of consent and were given a questionnaire concerning their language background. All were native speakers of Turkish living in the United States, attending the University of Kansas as undergraduate or graduate students. 5 participants were native speakers of Turkish with English as their main L2 while 1 participant was bilingual in Turkish and English, i.e. was raised speaking both languages since birth and has lived in both the United States and Turkey. The time during which they had been in the United States varied from 6 months to 10 years. All participants were from different cities in Turkey and all were speakers of standard Turkish.

2.2.2. Stimuli

The stimuli were divided into two parts. Part 1 was intended to compare fully–specified root vowels to underspecified suffix vowels. Pairs of words were used consisting of one disyllabic root ending in a vowel and one monosyllabic root plus a monosyllabic case suffix (either the dative –*A*, accusative –*I*, or locative –*DA*). The immediate phonological environment of the final vowel was the same for each member of a pair, e.g. [ho**bi**] '*hobby*' and [ʤe**b–i**] '*pocket*+ACC'.

Thus, each of the stimuli in Part 1 was disyllabic and ended in an open syllable which received stress. Final vowels in roots, regardless of the root's status as harmonic or disharmonic, were taken to be fully specified while those in suffixes were assumed to be underspecified for either backness alone (the dative and locative) or backness and rounding (the accusative). In all, the stimuli in Part 1 consisted of 58 pairs, with two repetitions per word, totaling 236 tokens.

Part 2 of the stimuli consisted of 48 words, each containing a root with a case ending attached. Again, each word ended in a stressed open syllable, but here the final vowel is in each case underspecified for either backness alone or both backness and rounding. In order to test the effect of the trigger vowel on the target vowel, each underspecified vowel appeared following two trigger vowels. The syllabic structure of the trigger vowel was controlled by including an equal number of tokens in which the trigger vowel occurred in an open syllable as in a closed syllable. Each trigger vowel and environment occurred twice, equaling a total of 8 words per underspecified vowel and 48 words in all. Thus, for example, for the accusative suffix [–i] which is underspecified for both backness and rounding (=/I/), the trigger vowels (/i e/) were used, the only possible trigger vowels in this case, leaving a total of 8 words, as shown below.

- Preceding closed syllable:

[ʧift–i] ‘*pair*+ACC’
[ʤilt–i] ‘*skin*+ACC’
[semt–i] ‘*neighborhood*+ACC’
[kent–i] ‘*city*+ACC’

- Preceding open syllable:

[bin–i] ‘*thousand*+ACC’
[tim–i] ‘*team*+ACC’
[ket–i] ‘*obstacle*+ACC’
[dem–i] ‘*breath/moment*+ACC’

Because we have predicted in Part 2 an effect for preceding vowel height in the high underspecified vowels, both possible trigger vowels for each high vowel have been used, i.e. in each case a high and a low vowel, such as in the example above. For the low underspecified vowels, however, an effect due to the roundedness of the preceding vowel was predicted and a high rounded and high unrounded trigger vowel have been used in each case. As in Part 1, each of the stimuli in Part 2 was read twice, totaling 96 tokens.

2.2.3. Recordings

Five speakers were recorded in the anechoic chamber at the University of Kansas using an Electro–Voice 767 microphone and a Marantz PMD 671 solid state recorder. One speaker was recorded offsite in a quiet environment using a portable Marantz PMD 671 solid state recorder. Recordings were made at a sampling rate of 22.05 kHz. Each target word was read twice in the carrier sentence [lytfen ____ søjlejin] '*please say* ___.' [2]

2.2.4. Measurements

All measurements were performed using PRAAT version 5.2.25 (Boersma, P. & Weenink, D. 2011). Files were spliced into separate files according to each vowel being compared for each of the two parts of the stimuli. Each file was annotated to a textgrid and target vowels were delineated on an interval tier.

Segmentation was performed using both the waveform and a wide–band spectrogram. Vowel onset was defined as the onset of periodicity following a voiceless consonant and the end of a burst where present. Following voiced stops, vowel onset was defined as the point at which F2 becomes clearly visible and the waveform abruptly becomes more complex. Where a burst

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[2] Preliminary consultation with informants suggested that this carrier sentence was the best formulation even though it is felt to be strange in Turkish. The reason for this is the inherent need to decline the object of the verb /søjlemek/ '*to say*.' Because the crucial comparison is between a declination ending containing an underspecified vowel and an undeclined root, there was seemingly no way around this. After actually participating in the study and reading the word list aloud, some informants indicated that a way around this would have been to add the word /kelime/ '*word*' essentially forming a compound, e.g. lytfen ____ kelimini søjlejin '*please say the word* ____'. However, while this may feel more natural to the participants, the primary focus and so strongest emphasis is no longer placed on the target word. Therefore, given that there is no perfect solution, it is assumed that the carrier sentence adopted is still the best choice.

was present, vowel onset immediately followed it. For voiced fricatives, vowel onset was taken as the point at which the waveform becomes more complex and less aperiodic accompanied by a clear strengthening of formant structure. An abrupt change from a weak formant structure was taken as the vowel onset when following a nasal (/m n/) or lateral (/l/) (Ladefoged 2006: 193, 196; Reez & Jongman 2009: 195). Following /r/, vowel onset was taken as the point at which F2 became clearly defined, which was usually accompanied by a preceding spike in high frequency energy. Where a brief spike in high energy was present at the boundary, vowel onset was taken to directly follow it. Following the glide /j/, vowel onset was taken as the point at which F2 begins to transition from a nearly steady state. Since all of the target vowels were followed by /s/, vowel offset was taken as the point at which high frequency aperiodic energy began to dominate the signal as indicated by an abrupt increase in zero–crossings (Jongman et al 2000).

Measurements of target vowels were taken using a script. F1, F2, and F3 were measured at the vowel onset, midpoint, and offset using a 20 ms Hamming window with a maximum formant frequency of 5500 Hz for the female speaker and 5000 Hz for the male speakers. The maximum number of formants was set at 5. Formant mistrackings were corrected individually by using a maximum number of formants setting of 6 and by manually verifying the results.

2.3. Results

2.3.1. Part I

Part 1 of the experiment was intended to test the hypothesis that underspecified vowels undershoot the phonetic correlates of the features for which they are underspecified by comparing underspecified suffix vowels to fully specified root vowels. It was predicted that two groups of vowels would pattern differently with respect to the effect of underspecification for backness, the front vowels [i y e] and the back vowels [ɯ u ɑ]. Namely, it was predicted that as a group, underspecified front vowels will have lower and back vowels higher F2 values compared to their fully specified counterparts.

The mean formant values at each point of measurement for each of the groups underspecified for backness, the front vowels and the back vowels, are listed in Tables 10 and 11 below respectively, along with the mean differences according to Specification. In the front vowels, little pattern can be discerned across all points of measurement. Interestingly, the direction of the difference due to underspecification was the same for each formant in the onset and offset, but exactly the opposite at the midpoint. Namely, in underspecified vowels, F1 fell in the onset and offset but rose at the midpoint, while F2 and F3 rose in the onset and offset but fell at the midpoint. In the back vowels, however, the direction of the effect of underspecification was consistent throughout the vowel. Specifically, F1 and F3 dropped while F2 rose in underspecified back vowels. As will be seen below, however, none of these differences were found to be significant.

Table 10: Mean formant values for [i y e] at each point of measurement according to Specification.

	[i y e]								
	Onset			Midpoint			Offset		
	Spec.	Under.	+/–	Spec.	Under.	+/–	Spec.	Under.	+/–
Mean F1	335 Hz	333 Hz	–2 Hz	316 Hz	359 Hz	+43 Hz	417 Hz	408 Hz	–9 Hz
Mean F2	1885 Hz	1910 Hz	+25 Hz	1877 Hz	1862 Hz	–15 Hz	1971 Hz	1990 Hz	+19 Hz
Mean F3	2601 Hz	2606 Hz	+5 Hz	2618 Hz	2604 Hz	–14 Hz	2837 Hz	2847 Hz	+10 Hz

Table 11: Mean formant values for [ɯ u ɑ] at each point of measurement according to Specification.

	[ɯ u ɑ]								
	Onset			Midpoint			Offset		
	Spec.	Under.	+/–	Spec.	Under.	+/–	Spec.	Under.	+/–
Mean F1	384 Hz	381 Hz	–3 Hz	412 Hz	405 Hz	–7 Hz	455 Hz	446 Hz	–9 Hz
Mean F2	1411 Hz	1452 Hz	+41 Hz	1350 Hz	1404 Hz	+54 Hz	1619 Hz	1637 Hz	+18 Hz
Mean F3	2666 Hz	2634 Hz	–32 Hz	2675 Hz	2658 Hz	–17 Hz	2890 Hz	2867 Hz	–23 Hz

Since underspecification for rounding is limited to the high vowels, it was predicted that for them alone an effect would be found. Unrounded high vowels ([i ɯ]) were expected to pattern together, as were the rounded high vowels ([y u]). Specifically, underspecified unrounded high vowels were predicted to have lower F3 values and rounded high vowels higher F3 values than their fully specified counterparts. The results show that F1 was lower in the underspecified versions of both high rounded and high unrounded vowels, while F2 and F3 were higher in the underspecified versions for the high unrounded vowels and lower for the high rounded vowels.

Tables 12 and 13 show the mean formant values at each point of measurement for each of the groups underspecified for backness, the high unrounded vowels and the high rounded vowels respectively. The only consistent direction of the effect of underspecification was that of F2, which rose throughout in the underspecified unrounded vowels and fell throughout in the underspecified rounded vowels, opposite of what we predicted. In the unrounded vowels, F3 rose throughout in the underspecified vowels. In the rounded vowels, however, F3 fell in the onset and midpoint, rising in the offset. In the unrounded vowels, F1 had no change in the onset, fell at the midpoint and then rose again at the offset, while in the rounded vowels it fell at the onset and offset but rose at the midpoint. Of all these differences, only those of F2 in the unrounded vowels were found to be significant in the following analyses and so are marked with an asterisk in Tables 12 and 13.

Table 12: Mean formant values for [i ɯ] at each point of measurement according to Specification.

	[i ɯ]								
	Onset			Midpoint			Offset		
	Spec.	Under.	+/–	Spec.	Under.	+/–	Spec.	Under.	+/–
Mean F1	327 Hz	327 Hz	0 Hz	340 Hz	337 Hz	–3 Hz	380 Hz	382 Hz	+2 Hz
Mean F2	1742 Hz	1779 Hz	*+37 Hz	1729 Hz	1754 Hz	*+25 Hz	1833 Hz	1863 Hz	*+30 Hz
Mean F3	2685 Hz	2696 Hz	+11 Hz	2711 Hz	2723 Hz	+12 Hz	2879 Hz	2909 Hz	+30 Hz

*Difference found to be significant.

Table 13: Mean formant values for [y u] at each point of measurement according to Specification.

	[y u]								
	Onset			Midpoint			Offset		
	Spec.	Under.	+/–	Spec.	Under.	+/–	Spec.	Under.	+/–
Mean F1	335 Hz	334 Hz	–1 Hz	333 Hz	329 Hz	+4 Hz	461 Hz	420 Hz	–41 Hz
Mean F2	1554 Hz	1537 Hz	–17 Hz	1509 Hz	1486 Hz	–23 Hz	1794 Hz	1756 Hz	–38 Hz
Mean F3	2592 Hz	2569 Hz	–23 Hz	2618 Hz	2604 Hz	–14 Hz	2829 Hz	2833 Hz	+4 Hz

The analyses above examined specification based on the groups of vowels that were predicted to pattern together with respect to the direction of the effect upon their formants due to underspecification for rounding and/or backness. In order to capture any possible differences between underspecified and specified vowels overall, i.e. outside of these groupings, differences between individual vowel pairs were examined as well. Tables 14 and 15 below show the mean formant values for each front vowel and each back vowel respectively at each point of measurement according to specification. While a number of different trends may be observed from vowel to vowel, we will focus on those found to be significant in the following analyses, which are marked with an asterisk. Namely, underspecified [i] had significantly higher F2 values at all three points of measurement compared to specified [i], while exactly the opposite was true of [u], i.e. underspecified [u] had significantly lower F2 values throughout. Lastly, underspecified [ɑ] was found to have significantly lower F2 values compared to its specified counterpart but only in the onset.

Table 14: Mean formant values at each point of measurement for each front vowel according to specification.

		[i]			[y]			[e]		
		Spec.	Under.	+/–	Spec.	Under.	+/–	Spec.	Under.	+/–
Onset	F1	309 Hz	308 Hz	–1 Hz	313 Hz	313 Hz	0 Hz	382 Hz	376 Hz	–6 Hz
	F2	1997 Hz	2046 Hz	*+49 Hz	1870 Hz	1863 Hz	–7 Hz	1783 Hz	1811 Hz	+28 Hz
	F3	2662 Hz	2676 Hz	+13 Hz	2560 Hz	2526 Hz	–34 Hz	2570 Hz	2599 Hz	+29 Hz
Mid	F1	321 Hz	320 Hz	–1 Hz	313 Hz	317 Hz	+4 Hz	432 Hz	434 Hz	+2 Hz
	F2	2037 Hz	2050 Hz	*+13 Hz	1808 Hz	1794 Hz	–14 Hz	1771 Hz	1729 Hz	–42 Hz
	F3	2715 Hz	2727 Hz	+12 Hz	2554 Hz	2530 Hz	–24 Hz	2570 Hz	2536 Hz	–34 Hz
Offset	F1	363 Hz	369 Hz	+3 Hz	445 Hz	408 Hz	–37 Hz	450 Hz	445 Hz	–5 Hz
	F2	2075 Hz	2106 Hz	*+31 Hz	1959 Hz	1963 Hz	+4 Hz	1879 Hz	1896 Hz	+17 Hz
	F3	2882 Hz	2910 Hz	+28 Hz	2783 Hz	2758 Hz	–25 Hz	2838 Hz	2856 Hz	+18 Hz

*Difference found to be significant.

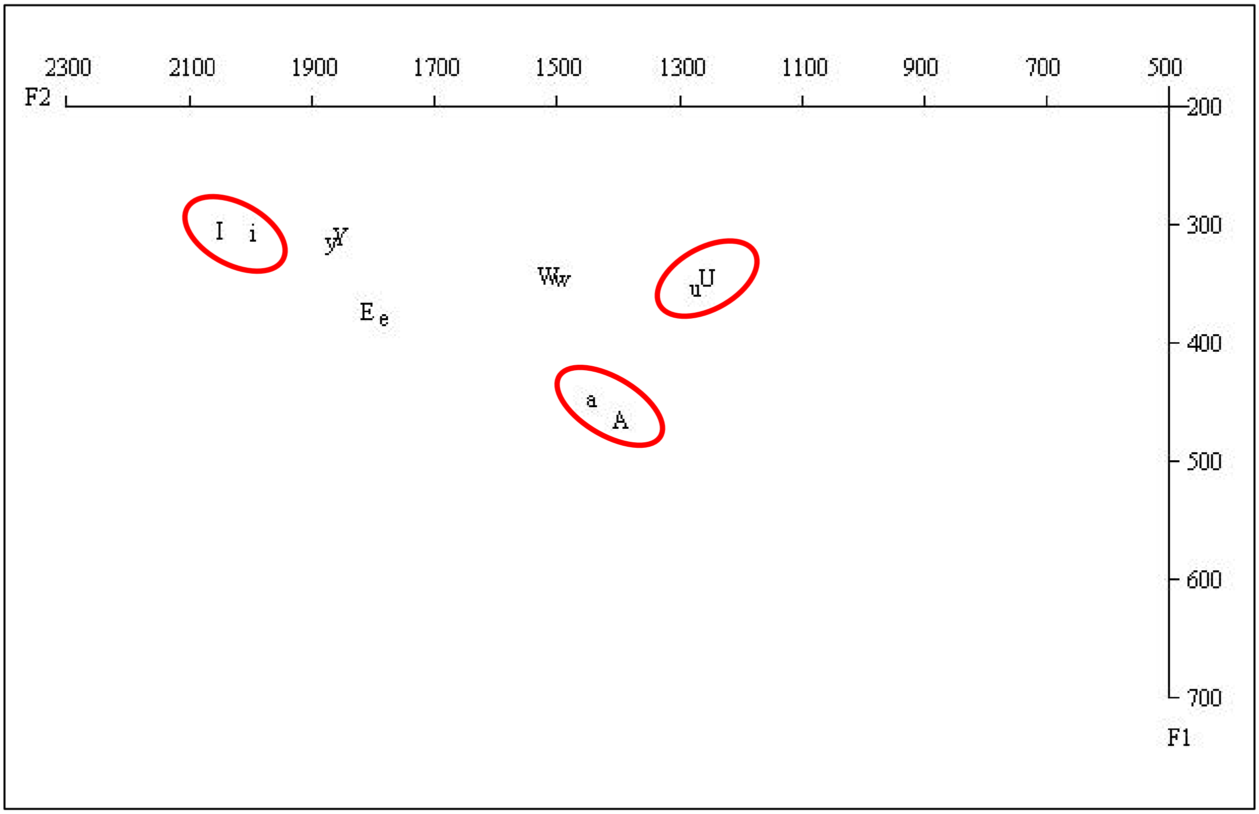
Table 15: Mean formant values at each point of measurement for each back vowel according to specification.

		[ɯ]			[u]			[ɑ]		
		Spec.	Under.	+/–	Spec.	Under.	+/–	Spec.	Under.	+/–
Onset	F1	348 Hz	345 Hz	–3 Hz	355 Hz	350 Hz	–5 Hz	448 Hz	470 Hz	+22 Hz
	F2	1492 Hz	1521 Hz	+29 Hz	1280 Hz	1256 Hz	*–24 Hz	1453 Hz	1395 Hz	*–58 Hz
	F3	2708 Hz	2716 Hz	+8 Hz	2620 Hz	2606 Hz	–14 Hz	2672 Hz	2597 Hz	–75 Hz
Mid	F1	359 Hz	354 Hz	–5 Hz	346 Hz	339 Hz	–7 Hz	531 Hz	540 Hz	+9 Hz
	F2	1427 Hz	1468 Hz	+41 Hz	1251 Hz	1220 Hz	*–31 Hz	1367 Hz	1351 Hz	–16 Hz
	F3	2707 Hz	2720 Hz	+13 Hz	2673 Hz	2666 Hz	–7 Hz	2651 Hz	2578 Hz	+27 Hz
Offset	F1	397 Hz	396 Hz	–1 Hz	479 Hz	429 Hz	–50 Hz	494 Hz	515 Hz	+21 Hz
	F2	1598 Hz	1629 Hz	+31 Hz	1654 Hz	1578 Hz	*–76 Hz	1602 Hz	1566 Hz	–46 Hz
	F3	2878 Hz	2910 Hz	+32 Hz	2870 Hz	2833 Hz	–37 HZ	2918 Hz	2823 Hz	–95 Hz

*Difference found to be significant.

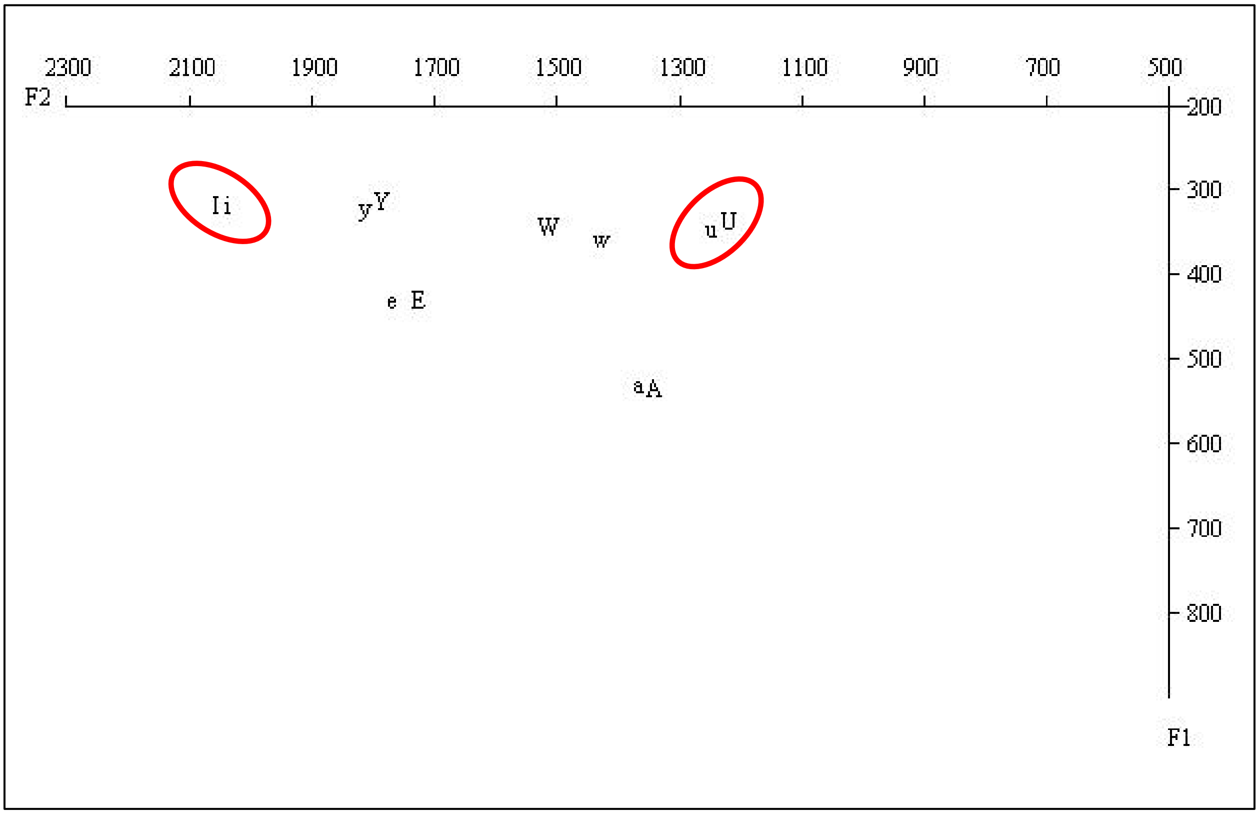
In order to better visualize these differences, Figures 2, 3 and 4 have been included below which show mean values of each vowel pair in a vowel space at the onset, midpoint and offset respectively. Vowel pairs in which a significant difference was found are marked with red ellipses, but again, effects were only significant upon F2 in all cases.

Figure 2: Vowel chart of mean values of F1 and F2 for specified and underspecified vowels at the onset



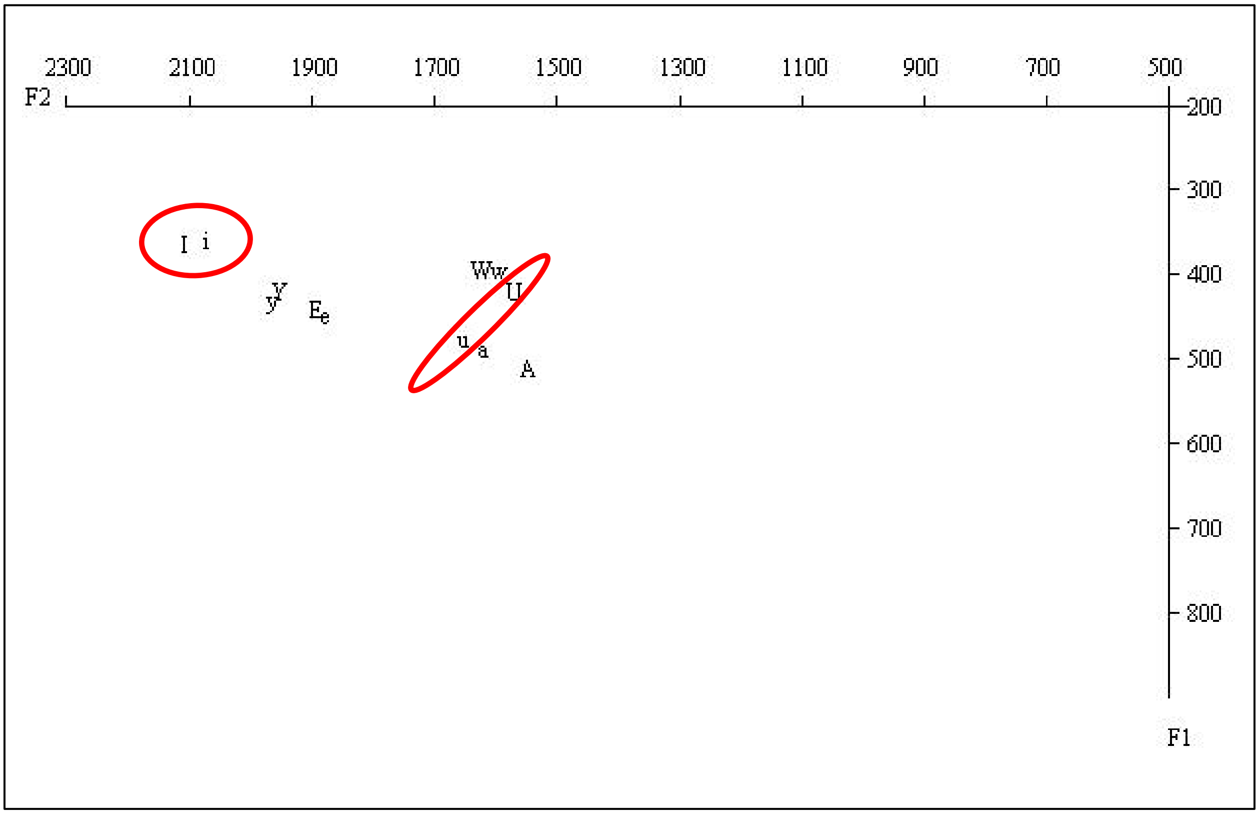
Uppercase letters represent underspecified vowels; w/W=[ɯ], a/A=[ɑ].

Figure 3: Vowel chart of mean values of F1 and F2 for specified and underspecified vowels at the midpoint



Uppercase letters represent underspecified vowels; w/W=[ɯ], a/A=[ɑ].

Figure 4: Vowel chart of mean values of F1 and F2 for specified and underspecified vowels at the offset



Uppercase letters represent underspecified vowels; w/W=[ɯ], a/A=[ɑ].

To determine the significance of the differences found between underspecified and specified found above, separate Repeated Measures ANOVAs were performed upon each group predicted to pattern together as well as each vowel pair using Specification and Place of Measurement as within-subjects variables for each formant (F1, F2 and F3). An alpha level was set at .05 for all analyses.

With respect to the front vowels and the back vowels, Place of Measurement was found to significant upon all formants for each both groups, except for F2 in the front vowels. No other significant effects were found for either group, indicating neither underspecified front vowels nor underspecified back vowels as a group differ significantly from their specified counterparts.

Analyses of the rounded and unrounded vowels, again, revealed a significant effect of Place of Measurement in both groups and for all formants. While no other significant effects were found for the rounded vowels, Specification did have a significant effect upon F2 in the unrounded vowels ($\lambda = .24$, $F\,(1, 5) = 15.81$, $p = .011$), indicating that underspecified unrounded vowels differ significantly from their specified counterparts in terms of F2.

With respect to the individual vowel pairs, the effect of Specification was significant upon F2 for both [i] ($\lambda = .16$, $F\,(1, 5) = 25.84$, $p = .004$) and [u] ($\lambda = .34$, $F\,(1, 5) = 9.79$, $p = .026$). Similarly, the effect of the interaction of Specification and Place of Measurement was significant upon F2 for [ɑ] ($\lambda = .17$, $F\,(2, 4) = 9.97$, $p = .028$. Further analyses upon each place of measurement showed that the effect of Specification in [ɑ] is limited to the onset ($F = 20.70$, $p = .006$). Thus, underspecified [i], [u] and [ɑ] differed in terms of F2 from their specified counterparts, throughout in the case of [i] and [u], and in the onset alone in the case [ɑ].

2.3.2. Part II

The stimuli in Part 2 were intended to test the alternative hypothesis that F2 and F3 vary according to those values in the trigger vowel itself. In this view, underspecified vowels can be divided into different groups based on the expected direction of their assimilation towards these values. With respect to F2, [i ɯ y] are predicted to have a lower F2 following low vowels, while the opposite is true of [u], i.e. it will have a higher F2 value following a low vowel. F3 is predicted to be lower in high unrounded vowels when following a low trigger vowel, while in the high rounded vowels it is predicted to be lower when the trigger vowel is high. The high vowels, therefore, are predicted to pattern differently with respect to F2 and F3 and so compose two groupings, F2–Grouping ([i ɯ y] versus [u]) and F3–Grouping ([i ɯ] versus [y u]). Both the low vowels ([e ɑ]) are expected to pattern the same way with respect to all three formants. Namely, they are predicted to have lower F2 values following rounded vowels, with no effect upon F1 or F3.

With respect to the F2–Grouping, only one effect was consistent at each point of measurement. Namely, F3 rose throughout in [i ɯ y] when the trigger vowel was low, while in [u] this was only the case at the midpoint and offset while it fell in the onset. In both [i ɯ y] and [u], F2 fell in the onset and midpoint, but rose in the offset, when preceded by a low vowel. In [i ɯ y], F1 rose in the onset and offset when the trigger vowel was low and fell at the midpoint, while in [u], F1 fell in the onset and midpoint and rose in the offset. Tables 16 and 17 below show the mean formant values for [i ɯ y] and [u] respectively at each point of measurement according to the height of the trigger vowel. The only differences found to be significant in the following analyses, however, were those of F2 for [u], which are marked with an asterisk.

Table 16: Mean formant values for [i ɯ y] of F2–Grouping at each place of measurement according to Preceding Vowel Height.

	[i ɯ y]								
	Onset			Midpoint			Offset		
	High	Low	+/–	High	Low	+/–	High	Low	+/–
Mean F1	328 Hz	333 Hz	+5 Hz	330 Hz	326 Hz	–4 Hz	417 Hz	426 Hz	+9 Hz
Mean F2	1738 Hz	1723 Hz	–15 Hz	1706 Hz	1700 Hz	–4 Hz	1850 Hz	1854 Hz	+4 Hz
Mean F3	2666 Hz	2678 Hz	+12 Hz	2651 Hz	2692 Hz	+41 Hz	2824 Hz	2856 Hz	+32 Hz

Table 17: Mean formant values for [u] of F2–Grouping at each place of measurement according to Preceding Vowel Height.

	[u]								
	Onset			Midpoint			Offset		
	High	Low	+/–	High	Low	+/–	High	Low	+/–
Mean F1	316 Hz	309 Hz	–7 Hz	325 Hz	299 Hz	–26 Hz	398 Hz	487 Hz	+89 Hz
Mean F2	1463 Hz	1355 Hz	*–108 Hz	1400 Hz	1322 Hz	*–78 Hz	1620 Hz	1719 Hz	*+99 Hz
Mean F3	2583 Hz	2567 Hz	–16 Hz	2558 Hz	2576 Hz	+18 Hz	2675 Hz	2729 Hz	+54 Hz

*Differences found to be significant.

With respect to F3–Grouping, F2 and F3 fell in the onset and rose in the midpoint and offset in [i ɯ] when the trigger vowel was low, while F1 rose in the onset and offset and fell at the midpoint. In [y u], F1 and F3 both rose throughout when the trigger vowel was low, while F2 rose in the onset and offset and fell at the midpoint. The mean formant values for [i ɯ] and [y u] respectively at each point of measurement according to the height of the trigger vowel are found below in Tables 18 and 19. None of these effects were found to be significant with respect to the groupings in the following analyses and so none are marked so.

Table 18: Mean formant values for [i ɯ] of F3–Grouping at each place of measurement according to Preceding Vowel Height.

	[i ɯ]								
	Onset			Midpoint			Offset		
	High	Low	+/–	High	Low	+/–	High	Low	+/–
Mean F1	335 Hz	339 Hz	+4 Hz	336 Hz	331 Hz	–5 Hz	404 Hz	427 Hz	+23 Hz
Mean F2	1723 Hz	1718 Hz	–5 Hz	1694 Hz	1709 Hz	+15 Hz	1844 Hz	1863 Hz	+19 Hz
Mean F3	2862 Hz	2691 Hz	–171 Hz	2696 Hz	2727 Hz	+31 Hz	2862 Hz	2896 Hz	+34 Hz

Table 19: Mean formant values for [y u] of F3–Grouping at each place of measurement according to Preceding Vowel Height.

	[y u]								
	Onset			Midpoint			Offset		
	High	Low	+/–	High	Low	+/–	High	Low	+/–
Mean F1	312 Hz	325 Hz	+13 Hz	322 Hz	321 Hz	+1 Hz	420 Hz	458 Hz	+38 Hz
Mean F2	1624 Hz	1561 Hz	+37 Hz	1558 Hz	1514 Hz	–44 Hz	1740 Hz	1776 Hz	+36 Hz
Mean F3	2620 Hz	2656 Hz	+36 Hz	2587 Hz	2630 Hz	+43 Hz	2741 Hz	2784 Hz	+43 Hz

In the low vowels, F3 rose consistently throughout when preceded by a rounded trigger vowel, while F2 dropped in the onset and midpoint and rose in the offset and F1 fell in the onset, had no change at the midpoint and rose in the offset. Table 20 below shows the mean formant values at each point of measurement according to the rounding of the trigger vowel. Only the difference in F2 in onset was found to be significant in the following analyses and so is marked with an asterisk.

Table 20: Mean formant values for the Low Vowels at each point of measurement according to Rounding of the Preceding Vowel.

	[ɑ e]								
	Onset			Midpoint			Offset		
	–Round	+Round	+/–	–Round	+Round	+/–	–Round	+Round	+/–
Mean F1	383 Hz	379 Hz	–4 Hz	474 Hz	474 Hz	0 Hz	491 Hz	494 Hz	+3 Hz
Mean F2	1614 Hz	1550 Hz	*–64 Hz	1517 Hz	1506 Hz	–11 Hz	1729 Hz	1736 Hz	+7 Hz
Mean F3	2674 Hz	2702 Hz	+28 Hz	2579 Hz	2609 Hz	+30 Hz	2839 Hz	2854 Hz	+15 Hz

*Difference found to be significant.

In order to determine the significance of the effects found due to the trigger vowel, Repeated Measures ANOVAs were performed for each group predicted to pattern together upon each formant (F1, F2 and F3). An alpha level was set at .05. For the groups belonging to F2-Grouping and to F3-Grouping, Preceding Vowel Height and Place of Measurement were used as within-subject factors. Of all the analyses performed upon each of these groups, significant effects of Preceding Vowel Height were found only for [u] in F2-Grouping. Namely, for [u] Preceding Vowel Height had a significant effect upon F2 (λ = .16, F (1, 4) = 20.62, p = .010), while the interaction of Preceding Vowel Height and Place of Measurement had a significant effect upon F1 (λ = .11, F (2, 3) = 12.41, p = .035). However, further analyses upon F1 at each place of measurement revealed no significant effects.

Finally, a Repeated Measures ANOVA was performed upon the low vowels using Rounding of Preceding Vowel and Place of Measurement as within-subject factors. The effect of the interaction of Rounding of Preceding Vowel and Place of Measurement was significant upon F2 (λ = .066, F (2, 4) = 25.12, p = .004). Further analyses upon F2 at each place of measurement revealed that the effect of Rounding of Preceding Vowel was significant only at the onset (F = 22.76, p = .005).

2.4. Discussion

It was hypothesized that vowels having undergone specification due to VH would undershoot the phonetic target values corresponding to the features for which they are underspecified which are associated with their fully specified counterparts. Specifically, it was predicted that underspecified front vowels ([i y e]) would have lower (*Prediction 1a*) and underspecified back vowels ([ɯ ɑ u]) higher F2 values (*Prediction 1b*) compared to their specified counterparts. Similarly, underspecified high rounded vowels ([y u]) will have higher (*Prediction 1c*) and underspecified high unrounded vowels ([i ɯ]) lower F3 values (*Prediction

1d) compared to their underspecified counterparts. Finally, no difference was expected in F1 between any underspecified vowels and their specified counterparts (*Prediction 1e*).

When grouped for backness, underspecified vowels did not differ significantly from their specified counterparts with respect to any of the formants. These results do not support *Predictions 1a* and *1b*. When grouped for rounding, however, significant differences were found. Underspecified high unrounded vowels had significantly *higher* F2 values at each place of measurement compared to specified high unrounded vowels, while no significant differences were found for the underspecified high rounded. This is contrary to *Predictions 1c* and *1d*, which predicted exactly the opposite trend and with F3. Neither when grouped for backness nor when grouped for rounding, was any significant effect upon F1 found involving specification, which lends support to *Prediction 1e*.

Except for Prediction 1e, all of our predictions were concerned with vowel groupings according to either backness or rounding. However, differences in F1, F2 and F3 due to specification according to each vowel pair were examined as well in order to capture any significant differences that might be present outside these groupings. Interestingly, and unexpectedly according to our predictions, significant differences were found for [i], [u], and [ɑ], in each case in terms of F2. Namely, underspecified [i] had significantly *higher* F2 values at all three points of measurement compared to specified [i], while underspecified [u] had significantly *lower* F2 values throughout. Lastly, underspecified [ɑ] was found to have significantly *lower* F2 values compared to its specified counterpart but only in the onset. In all three cases, this is opposite the direction of the effect of underspecification that was predicted. Again, now effect upon F1 was found.

In summary, no significant differences were found due to underspecification for backness. Underspecification for rounding, however, caused a significant rise in F2 at all three points of measurement in the high unrounded vowels compared to their specified counterparts, opposite what was predicted. Of the individual vowels pairs, underspecified [i] had significantly higher and [u] significantly lower F2 values at all points of measurement, while for [ɑ] F2 was significantly lower only in the onset. None of the results support *Predictions 1a–d*. The results for each group and the individual pairs all support *Prediction 1e*, which is the only prediction supported.

Table 21: Summary of Part 1 predictions and conclusions.

Prediction	Predicted effect	Effect found	Conclusion
Prediction 1a —	Underspecified front vowels ([i y e]) will have *lower* F2 values compared to their specified counterparts	No significant effect.	Effect of underspecification for backness is not significant upon F2
Prediction 1b —	Underspecified back vowels ([ɯ ɑ u]) will have *higher* F2 values compared to their specified counterparts	No significant effect	
Prediction 1c —	Underspecified high rounded vowels ([y u]) will have *higher* F3 values compared to their specified counterparts	No significant effect	Effect of underspecification for rounding is significant upon F2, only for the unrounded vowels and not upon F3.
Prediction 1d —	Underspecified high unrounded vowels ([i ɯ]) will have *lower* F3 values compared to their fully specified counterparts	Underspecified high unrounded vowels ([i ɯ]) have significantly *higher* F2 values throughout compared to their fully specified counterparts	
Prediction 1e +	No differences will be found for values of F1 between underspecified and specified vowels	No significant effects upon F1	Underspecification for backness and for rounding do not significantly effect F1

The intention of Part 2 of the experiment was to test the alternative hypothesis that specification in Turkish is an assimilatory process in which the target vowels assimilate to trigger vowels with respect to the phonetic correlates for the features for which they are underspecified.

Using vowel formant values previously reported in the literature, we predicted essentially three patterns. First, it was predicted that effect upon F3 of the trigger vowel would be limited to the high vowels because only they lack specification for rounding. Specifically, the high unrounded vowels ([i ɯ]) were predicted to have lower F3 values when following low vowels compared to when they follow high vowels (*Prediction 2d*) while exactly the opposite was predicted for the high rounded vowels ([y u]) (*Prediction 2e*). With respect to F2, lower values were predicted for [i ɯ y] when the trigger vowel is a low vowel compared to a high vowel (*Prediction 2a*), while for [u] lower values are expected when following a high vowel (*Prediction 2b*). The effect of the trigger vowel upon F2 in the low vowels ([e ɑ]), however, is predicted to vary according to the rounding of the trigger vowel. Specifically, both low vowels are expected to have lower F2 values when following rounded vowels compared to when following unrounded vowels (*Prediction 2c*).

With respect to the high vowels, the only significant effect of the height of the trigger vowel was for either the grouping for F2 ([i ɯ y] vs. [u]) or the grouping for F3 ([i ɯ] vs. [u y]), was upon F2 for [u]. Specifically, [u] had significantly *lower* F2 values in the onset and midpoint and *higher* F2 values at the offset when preceded by a low trigger vowel, lending support to *Prediction 2b*. *Predictions 2a*, *2d*, and *2e* are not supported. As no effect was found to be significant upon F1, *Prediction 2f* is also supported by these results.

Concerning the low vowels, results indicated that F2 was significantly *lower* in the onset when the trigger vowel was rounded compared to when in was unrounded, lending support to *Prediction 2c*. As no significant effect was found upon F1 or F3, these results lend support to *Prediction 2f*.

In summary, significant effects of the height of the trigger vowel were found only upon F2. For [u], F2 was lower in the onset and midpoint and higher in the offset when the trigger vowel was low. Similarly, the effect of the rounding of the trigger vowel was found to significantly lower F2 in the low vowels in the onset. Table 23 summarizes the effects found and conclusions regarding each prediction.

Table 22: Summary of Part 2 predictions and conclusions.

Prediction	Predicted effect	Effect found	Conclusion
Prediction 2a —	For [i ɯ y], F2 will be *lower* when the trigger vowel is *low*	F2 is significantly *lower* in the onset when trigger vowel is *low*, but only outside of the groupings	Height of the trigger vowel significantly affects F2, but only in [u]
Prediction 2b ✓	For [u], F2 will be *lower* when the trigger vowel is *high*		
Prediction 2c ✓	For the low vowels ([ɑ e]), F2 will be *lower* when the trigger vowel is a *rounded*	F2 is significantly *lower* in the onset when trigger vowel is *rounded*	Rounding of the trigger vowel significantly affects F2 in the onset of low underspecified vowels
Prediction 2d —	For high unrounded vowels ([i ɯ]), F3 will be *lower* when the trigger vowel is *low*	No significant effect.	Height of the trigger vowel does not significantly affect F3 in high vowels.
Prediction 2e —	For high rounded vowels ([y u]), F3 will be *lower* when the trigger vowel is *high*		
Prediction 2f ✓	No effect of the trigger vowel will be found upon F3 for the low vowels ([ɑ e]) or upon F1 for any vowel	No significant effect was found upon F1 or F3 for any group	Rounding of the trigger vowel does not significantly affect F1 or F3 in low vowels.

3. Conclusions

This goal of this study was to investigate the possibility that underspecification in Turkish suffix vowels may persist into their acoustic realization as evidenced by quantitative differences in the quality of fully specified root vowels compared to underspecified suffix vowels. In order to do so, we based our investigation on the hypothesis that specification due to VH in Turkish is a partial, dynamic, categorical process. It is partial in that we predicted that specification is not complete, leaving quantitative differences between underlyingly underspecified and specified vowels even after specification. It is dynamic because we expect to find differences in the proximity to the target values according to the distance from the trigger vowel, i.e. the greater proximity to the target values is predicted at the offset of the target vowel compared to the onset. Lastly, it is categorical in that the target vowel does not assimilate to the phonetic values of the trigger vowel itself; rather, the trigger vowel determines the vowel category to which the target vowel will attempt to equate. Namely, it is the acoustic properties of this vowel category corresponding to the underspecified features that the target vowel will approximate but ultimately undershoot.

Based on this hypothesis, it was predicted that the direction of the effect of undershoot due to underspecification would depend on the feature for which each vowel was underspecified. The front vowels ([i y e]) were predicted to have lower F2 values than their fully specified counterparts since they do not fully reach the F2 values associated with the specified front vowels. Likewise, the back vowels ([ɯ u ɑ]) were predicted to have higher F2 values than their fully specified counterparts, undershooting those F2 values associated with specified back vowels. Since only the high vowels are underspecified for rounding, it was predicted that only they will undershoot the F3 values associated with their fully specified counterparts. The high unrounded vowels ([i ɯ]) were predicted to have lower F3 values than their fully specified counterparts, while the high rounded vowels ([y u]) were thought to have higher F3 values than those of their fully specified counterparts. With respect to F1, our hypothesis predicts that there will be no effect found because vowels in Turkish are not underspecified for height.

The results of Part 1 of the experiment indicated that there are quantitative differences in the acoustic signal between fully specified and underspecified vowels. They did not, however, match up fully with our predictions. Underspecification for backness did not significantly affect any formants, i.e. underspecified front vowels were not significantly different from their specified counterparts, nor were underspecified back vowels. Underspecification for rounding, however, did significantly affect F2, though not F3 and only for the unrounded vowels. Namely, underspecified unrounded vowels had significantly higher F2 values throughout the vowel compared to their specified counterparts. This is contrary to our predictions, according to which we expected exactly the opposite effect and in F3 rather than F2.

In addition to the effect of underspecification for rounding, underspecification alone (i.e. regardless of the type) had significant effects upon [i], [u], and [ɑ]. Underspecified [i] had significantly higher F2 values and [u] significantly lower F2 values throughout their entirety, while [ɑ] had significantly lower F2 values in the onset alone. As in the case of the unrounded vowels, the direction of the effects found were opposite what we predicted.

However, one question that must be asked, is why were significant effects found only for [i], [u] and [ɑ]. In the case of [i] and [u], it becomes readily apparent when reexamining Table 4. It was predicted that the effect of underspecification for backness would lower F2 in the front vowels and raise F2 in the back vowels, the effect while underspecification for rounding would raise F2 and F3 in the rounded vowels and lower them in the unrounded vowels. As discussed earlier, there is a contradiction in the predicted effects upon F2 in [ɯ] and [y], while both effects work in the same direction in terms of F2 in [i] and [u], just opposite the direction predicted. With respect to [ɑ], however, it is difficult to say why and effect was found, but not in [e].

Returning to our predictions, it was predicted that specification was incomplete, categorical and dynamic. With respect to the dynamicity, our results only indicated a dynamic effect in the case of [ɑ], in which F2 only differed significantly in the onset, while all other results point to a process of specification which is uniform throughout the vowel.

It was hypothesized that specification is an incomplete process. We cannot posit an incomplete process of specification based on our results. All of the significant effects of underspecification, rather than cases of undershoot as predicted, could be termed *overshoot*. That is, if specification does start from a neutral position with respect to the values corresponding to the features for which they are underspecified, then it goes even further than the target values associated with the specified vowels, overshooting them. Thus, far from being incomplete, specification reaches its targets and passes them.

In order to lend further support to any findings that might be obtained, a second set of stimuli was used to test an alternative hypothesis. According to this hypothesis, specification is a partial, dynamic but assimilatory rather than categorical process. Through specification vowels assimilate with respect to the phonetic correlates for which they are underspecified to the trigger vowels themselves rather than a particular vowel category, still ultimately undershooting the values of the trigger vowel, to a greater extent as the distance from the trigger vowel increases.

Based on the alternative hypothesis it was predicted that for underspecified [i ɯ y] F2 will be lower when the trigger vowel is low, due to the lower F2 values in the trigger vowel itself, whereas for [u] F2 will be lower following a high vowel because F2 is lower for the trigger vowel [u] than for [o]. For the low vowels ([ɑ e]) were predicted to have lower F2 values when following a rounded trigger vowel. As in Part 1, an effect involving F3 was predicted only for the high vowels because only they are underspecified for rounding. F3 values were predicted to be lower in high unrounded vowels ([i ɯ]) when the trigger vowel is low and lower in high rounded vowels when the trigger vowel is high.

As with the predictions for Part 1, results were mixed. For the high vowels, a significant effect of the height of the trigger vowel was found only for [u], which had significantly lower F2 values throughout when the trigger vowel was low. The low vowels had significantly lower F2 values in the onset when the trigger vowel was rounded compared to when it was not. With respect to dynamicity, the results are mixed. The effect found upon [u] affected the entirety of the vowel, while rounding of the trigger vowel affected only the onset of the low vowels. Given these results, we proposed that these effects found are due to coarticulation, which, though dynamic, may also affect the entirety of the vowel.

It may seem that the results from Part 2 contradict in a way those of Part 1. However, acoustic differences resulting from incomplete specification do not necessarily rule out effects due to coarticulation, such as those found in Part 2. Given these results, we posit that specification and coarticulation are two separate processes in Turkish. Specification is a process in which the target vowel approximates a psychological target and its associated physical attributes, whereas coarticulation is an assimilatory process derived from inevitable physical effects of moving from one physical target to the next. Therefore, in addition to the coarticulatory effects of the trigger vowel found in Part 2, we have shown that there are quantitative acoustic differences between underlyingly specified and underspecified vowels even after specification. Additionally, our results do *not* indicate that specification is a dynamic, gradual process, while coarticulation in Turkish is.

One important question remains to be dealt with yet. Why would specification overshoot its target values? One possible explanation is that in this way, the features for which the target vowel is underspecified will be more likely to be correctly perceived. This has been referred to as perceptual enhancement by Kaun, who, following Suomi (1983), sees this as one of the major driving forces behind vowel harmony itself (2004: 95-6). Thus, it may be that specification through vowel harmony in Turkish, and perhaps elsewhere, leads to overshoot of the feature values associated with supposedly identical specified vowels in order to assure their maximal perception by the listener.

In conclusion, we have shown that specification in Turkish is a generally uniform process in which the entire vowel is affected in the same way. Specification for backness was shown to be complete throughout the vowel, while specification for rounding was complete in the rounded high vowels while the unrounded high vowels overshot their target values, leaving quantitative differences between underlyingly specified and underspecified vowels in their surface forms. Additionally, we have shown that underspecified vowels in Turkish are subject to coarticulatory effects from trigger vowels, but that this process is separate from that of specification itself, which is a process in which the target vowel assimilates to an abstract category associated with concrete physical targets, i.e. those present in the specified version of that vowel category.

While coarticulation is nothing new and has a vast body of research behind it, a simple comparison of underspecified vowels and their underspecified counterparts is new. The most important contribution of this study is that we have shown that there are quantitative, statistically significant differences in the acoustic signal between underlyingly underspecified and specified vowels, despite their supposed identicalness of their surface forms.

4. References

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5. Appendix A: Statistical Results

5.1. Part 1

* indicates results found to be significant according to an alpha level of .05

Table 23: Front Vowels – F1

Effect	Wilks' λ	Hypothesis *df*	Error *df*	*F*	*p*
Specification	.83	1	5	1.05	.35
Place of Measurement	.057	2	4	33.20	*.003
Specification x Place of Measurement	.84	2	4	.38	.71

Table 24: Front Vowels – F2

Effect	Wilks' λ	Hypothesis *df*	Error *df*	*F*	*p*
Specification	.76	1	5	1.57	.26
Place of Measurement	.30	2	4	4.79	.087
Specification x Place of Measurement	.53	2	4	1.80	.28

Table 25: Front Vowels – F3

Effect	Wilks' λ	Hypothesis *df*	Error *df*	*F*	*p*
Specification	1.00	1	5	.003	.96
Place of Measurement	.14	2	4	12.66	*.019
Specification x Place of Measurement	.75	.66	2	4	.56

Table 26: Back Vowels – F1

Effect	Wilks' λ	Hypothesis *df*	Error *df*	*F*	*p*
Specification	.78	1	5	1.40	.29
Place of Measurement	.12	2	4	14.78	*.014
Specification x Place of Measurement	.59	2	4	1.40	.35

Table 27: Back Vowels – F2

Effect	Wilks' *λ*	Hypothesis *df*	Error *df*	*F*	*p*
Specification	.92	1	5	.44	.54
Place of Measurement	.052	2	4	36.57	*.003
Specification x Place of Measurement	.40	2	4	2.95	.16

Table 28: Back Vowels – F3

Effect	Wilks' *λ*	Hypothesis *df*	Error *df*	*F*	*p*
Specification	.86	1	5	.83	.40
Place of Measurement	.13	2	4	13.82	*.016
Specification x Place of Measurement	.69	2	4	.90	.48

Table 29: Rounded Vowels – F1

Effect	Wilks' *λ*	Hypothesis *df*	Error *df*	*F*	*p*
Specification	.67	1	5	2.46	.18
Place of Measurement	.21	2	4	7.67	*.043
Specification x Place of Measurement	.49	2	4	2.05	.27

Table 30: Rounded Vowels – F2

Effect	Wilks' *λ*	Hypothesis *df*	Error *df*	*F*	*p*
Specification	.49	1	5	5.18	.072
Place of Measurement	.060	2	4	31.60	*.004
Specification x Place of Measurement	.88	2	4	.28	.77

Table 31: Rounded Vowels – F3

Effect	Wilks' *λ*	Hypothesis *df*	Error *df*	*F*	*p*
Specification	.96	1	5	.23	.65
Place of Measurement	.025	2	4	78.99	*.001
Specification x Place of Measurement	.82	2	4	.42	.68

Table 32: Unrounded Vowels – F1

Effect	Wilks' *λ*	Hypothesis *df*	Error *df*	*F*	*p*
Specification	1.00	1	5	.025	.88
Place of Measurement	.21	2	4	7.45	*.045
Specification x Place of Measurement	.83	2	4	.41	.69

Table 33: Unrounded Vowels – F2

Effect	Wilks' *λ*	Hypothesis *df*	Error *df*	*F*	*p*
Specification	.24	1	5	15.81	*.011
Place of Measurement	.17	2	4	9.57	*.030
Specification x Place of Measurement	.67	2	4	.98	.45

Table 34: Unrounded Vowels – F3

Effect	Wilks' *λ*	Hypothesis *df*	Error *df*	*F*	*p*
Specification	.65	1	5	2.70	.16
Place of Measurement	.14	2	4	11.95	*.021
Specification x Place of Measurement	.90	2	4	.22	.81

Table 35: [i] – F1

Effect	Wilks' *λ*	Hypothesis *df*	Error *df*	*F*	*p*
Specification	.98	1	5	.11	.78
Place of Measurement	.16	2	4	10.80	*.024
Specification x Place of Measurement	.95	2	4	.11	.90

Table 36: [i] – F2

Effect	Wilks' *λ*	Hypothesis *df*	Error *df*	*F*	*p*
Specification	.16	1	5	25.84	*.004
Place of Measurement	.52	2	4	1.87	.27
Specification x Place of Measurement	.62	2	4	1.25	.38

Table 37: [i] – F3

Effect	Wilks' *λ*	Hypothesis *df*	Error *df*	*F*	*p*
Specification	.47	1	5	5.61	.064
Place of Measurement	.18	2	4	8.88	*.034
Specification x Place of Measurement	.94	2	4	.13	.88

Table 38: [e] – F1

Effect	Wilks' *λ*	Hypothesis *df*	Error *df*	*F*	*p*
Specification	.98	1	5	.12	.75
Place of Measurement	.63	2	4	29.78	*.004
Specification x Place of Measurement	.65	2	4	1.09	.42

Table 39: [e] – F2

Effect	Wilks' *λ*	Hypothesis *df*	Error *df*	*F*	*p*
Specification	1.00	1	5	.005	.95
Place of Measurement	.17	2	4	9.94	*.028
Specification x Place of Measurement	.63	1.20	2	4	.39

Table 40: [e] – F3

Effect	Wilks' *λ*	Hypothesis *df*	Error *df*	*F*	*p*
Specification	.97	1	5	.14	.72
Place of Measurement	.13	2	4	13.44	*.017
Specification x Place of Measurement	.54	2	4	1.69	.29

Table 41: [y] – F1

Effect	Wilks' *λ*	Hypothesis *df*	Error *df*	*F*	*p*
Specification	.92	1	5	.44	.53
Place of Measurement	.20	2	4	8.20	*.038
Specification x Place of Measurement	.85	2	4	.36	.72

Table 42: [y] – F2

Effect	Wilks' λ	Hypothesis *df*	Error *df*	*F*	*p*
Specification	.98	1	5	.10	.76
Place of Measurement	.091	2	4	19.94	*.008
Specification x Place of Measurement	.87	2	4	.29	.76

Table 43: [y] – F3

Effect	Wilks' λ	Hypothesis *df*	Error *df*	*F*	*p*
Specification	.73	1	5	1.85	.23
Place of Measurement	.032	2	4	60.44	*.001
Specification x Place of Measurement	.58	2	4	1.46	.34

Table 44: [ɯ] – F1

Effect	Wilks' λ	Hypothesis *df*	Error *df*	*F*	*p*
Specification	.89	1	5	.60	.47
Place of Measurement	.37	2	4	3.33	.14
Specification x Place of Measurement	.96	2	4	.094	.91

Table 45: [ɯ] – F2

Effect	Wilks' λ	Hypothesis *df*	Error *df*	*F*	*p*
Specification	.52	1	5	4.61	.084
Place of Measurement	.039	2	4	49.80	*.001
Specification x Place of Measurement	.73	2	4	.75	.53

Table 46: [ɯ] – F3

Effect	Wilks' λ	Hypothesis *df*	Error *df*	*F*	*p*
Specification	.84	1	5	.98	.37
Place of Measurement	.23	2	4	6.83	.051
Specification x Place of Measurement	.90	2	4	.22	.81

Table 47: [u] – F1

Effect	Wilks' λ	Hypothesis *df*	Error *df*	*F*	*p*
Specification	.50	1	5	5.02	.075
Place of Measurement	.72	2	4	5.22	.077
Specification x Place of Measurement	.52	2	4	1.83	.27

Table 48: [u] – F2

Effect	Wilks' λ	Hypothesis *df*	Error *df*	*F*	*p*
Specification	.34	1	5	9.79	*.026
Place of Measurement	.061	2	4	30.98	*.004
Specification x Place of Measurement	.70	2	4	.85	.49

Table 49: [u] – F3

Effect	Wilks' λ	Hypothesis *df*	Error *df*	*F*	*p*
Specification	.95	1	5	.26	.63
Place of Measurement	.046	2	4	41.84	*.002
Specification x Place of Measurement	.50	2	4	1.99	.25

Table 50: [ɑ] – F1

Effect	Wilks' λ	Hypothesis *df*	Error *df*	*F*	*p*
Specification	.55	1	5	4.09	.099
Place of Measurement	.033	2	4	58.84	*.001
Specification x Place of Measurement	.59	2	4	1.37	.35

Table 51: [ɑ] – F2

Effect	Wilks' λ	Hypothesis *df*	Error *df*	*F*	*p*
Specification	.65	1	5	2.72	.16
Place of Measurement	.10	2	4	17.52	*.010
Specification x Place of Measurement	.17	2	4	9.97	*.028

Table 52: [ɑ] – F2 at each point of measurement

Source	Place of Measurement	*df*	Mean Square	*F*	*p*
Specification	Onset	1	9964.23	20.70	*.006
	Midpoint	1	812.14	3.17	.14
	Offset	1	3903.86	.44	.54

Table 53: [ɑ] – F3

Effect	Wilks' *λ*	Hypothesis *df*	Error *df*	*F*	*p*
Specification	.66	1	5	2.62	.17
Place of Measurement	.12	2	4	15.03	*.014
Specification x Place of Measurement	.90	2	4	.22	.81

5.2. Part 2

* indicates results found to be significant according to an alpha level of .05

Table 54: [i ɯ y] – F1

Effect	Wilks' *λ*	Hypothesis *df*	Error *df*	*F*	*p*
Specification	.95	1	5	.28	.62
Place of Measurement	.40	2	4	2.99	.16
Specification x Place of Measurement	.63	2	4	1.17	.40

Table 55: [i ɯ y] – F2

Effect	Wilks' *λ*	Hypothesis *df*	Error *df*	*F*	*p*
Specification	.98	1	5	.11	.76
Place of Measurement	.079	2	4	23.38	*.006
Specification x Place of Measurement	.80	2	4	.51	.84

Table 56: [i ɯ y] – F2

Effect	Wilks' *λ*	Hypothesis *df*	Error *df*	*F*	*p*
Preceding Vowel Height	.47	1	5	5.55	.065
Place of Measurement	.35	2	4	3.74	.12
Preceding Vowel Height x Place of Measurement	.46	2	4	2.31	.22

Table 57: [u] – F1

Effect	Wilks' *λ*	Hypothesis *df*	Error *df*	*F*	*p*
Preceding Vowel Height	.94	1	4	.27	.63
Place of Measurement	.42	2	3	2.11	.27
Preceding Vowel Height x Place of Measurement	.11	2	3	12.41	*.035

Table 58: [u] – F1 at each point of measurement

Source	Place of Measurement	*df*	Mean Square	*F*	*p*
Preceding Vowel Height	Onset	1	134.77	.18	.70
	Midpoint	1	1627.71	1.50	.29
	Offset	1	19884.23	1.28	.32

Table 59: [u] – F2

Effect	Wilks' *λ*	Hypothesis *df*	Error *df*	*F*	*p*
Preceding Vowel Height	.16	1	4	20.62	*.010
Place of Measurement	.092	2	3	14.79	*.028
Preceding Vowel Height x Place of Measurement	.41	2	3	2.15	.26

Table 60: [u] – F3

Effect	Wilks' *λ*	Hypothesis *df*	Error *df*	*F*	*p*
Preceding Vowel Height	.92	1	4	.32	.60
Place of Measurement	.18	2	3	7.00	.074
Preceding Vowel Height x Place of Measurement	.67	2	3	.72	.55

Table 61: [i ɯ] – F1

Effect	Wilks' *λ*	Hypothesis *df*	Error *df*	*F*	*p*
Preceding Vowel Height	.88	1	5	.66	.45
Place of Measurement	.47	2	4	2.24	.22
Preceding Vowel Height x Place of Measurement	.39	2	4	3.14	.15

Table 62: [i ɯ] – F2

Effect	Wilks' *λ*	Hypothesis *df*	Error *df*	*F*	*p*
Preceding Vowel Height	.98	1	5	.10	.76
Place of Measurement	.094	2	4	19.38	*.009
Preceding Vowel Height x Place of Measurement	.863	2	4	.32	.75

Table 63: [i ɯ] – F3

Effect	Wilks' *λ*	Hypothesis *df*	Error *df*	*F*	*p*
Preceding Vowel Height	.81	1	5	1.20	.32
Place of Measurement	.45	2	4	2.43	.20
Preceding Vowel Height x Place of Measurement	.34	2	4	3.81	.12

Table 64: [y u] – F1

Effect	Wilks' *λ*	Hypothesis *df*	Error *df*	*F*	*p*
Preceding Vowel Height	.85	1	5	.91	.38
Place of Measurement	.29	2	4	4.87	.085
Preceding Vowel Height x Place of Measurement	.73	2	4	.75	.53

Table 65: [y u] – F2

Effect	Wilks' *λ*	Hypothesis *df*	Error *df*	*F*	*p*
Preceding Vowel Height	.90	1	5	.54	.49
Place of Measurement	.11	2	4	16.04	*.012
Preceding Vowel Height x Place of Measurement	.54	2	4	1.70	.29

Table 66: [y u] – F3

Effect	Wilks' *λ*	Hypothesis *df*	Error *df*	*F*	*p*
Preceding Vowel Height	.67	1	5	2.60	.17
Place of Measurement	.079	2	4	23.32	*.006
Preceding Vowel Height x Place of Measurement	.97	2	4	.065	.94

Table 67: [ɑ e] – F1

Effect	Wilks' *λ*	Hypothesis *df*	Error *df*	*F*	*p*
Rounding of Preceding Vowel	1.00	1	5	.001	.97
Place of Measurement	.23	2	4	6.61	.054
Rounding of Preceding Vowel x Place of Measurement	.85	2	4	.35	.72

Table 68: [ɑ e] – F2

Effect	Wilks' *λ*	Hypothesis *df*	Error *df*	*F*	*p*
Rounding of Preceding Vowel	.76	1	5	1.62	.26
Place of Measurement	.22	2	4	7.08	*.048
Rounding of Preceding Vowel x Place of Measurement	.066	2	4	28.12	*.004

Table 69: [ɑ e] – F2 at each point of measurement

Source	Place of Measurement	*df*	Mean Square	*F*	*p*
Rounding of Preceding Vowel	Onset	1	12303.42	22.76	*.005
	Midpoint	1	375.31	.11	.75
	Offset	1	162.50	.21	.66

Table 70: [ɑ e] – F3

Effect	Wilks' *λ*	Hypothesis *df*	Error *df*	*F*	*p*
Rounding of Preceding Vowel	.72	1	5	1.90	.23
Place of Measurement	.21	2	4	7.44	*.045
Rounding of Preceding Vowel x Place of Measurement	.81	2	4	.46	.66

6. Appendix B: Stimuli

6.1. Part 1

/i/		[i] < /I/	
[hobi]	'*hobi*'	[ceb–i]	'*pocket*+ACC'
[terzi]	'*tailor*'	[iz–i]	'*footprint*+ACC'
[ʧivi]	'*nail*'	[ev–i]	'*house*+ACC'
[baji]	'*franchiser*'	[ʃej–i]	'*thing*+ACC'
[tirsi]	'*twaite*'	[ders–i]	'*class*+ACC'
[sini]	'*copper tray*'	[bin–i]	'*building*+ACC'
[gemi]	'*ship*'	[sim–i]	'*silver*+ACC'
[kedi]	'*cat*'	[ʤild–i]	'*skin*/*binding*+ACC'
[deri]	'*skin*/*leather*	[jer–i]	'*place*/*floor*+ACC'
[mersi]	'*thank you*'	[is–i]	'*soot*+ACC'

/ɯ/		[ɯ] < /I/	
[ɑyɯ]	'*bear*'	[bɑy–ɯ]	'*genleman*+ACC'
[kɑpɯ]	'*door*'	[hɑp–ɯ]	'*pill*+ACC'
[ɯsɯ]	'*heat, warmth*'	[ɑs–ɯ]	'*ace*+ACC'
[ɑɯ]	'*poison*'	[bɑ–ɯ]	'*tie/string*+ACC'
[tɑnɯ]	'*diagnosis*'	[hɑn–ɯ]	'*caravansary*+ACC'
[pɑzɯ]	'*chard*'	[kɯz–ɯ]	'*daughter/girl*+ACC'
[tɑnrɯ]	'*God*'	[sɯr–ɯ]	'*glaze*+ACC'
[mɑzɯ]	'*arborvitae*/*gallnut*'	[gɑz–ɯ]	'*gas*+ACC'
[dɑjɯ]	'*maternal uncle*'	[tɑj–ɯ]	'*one of a pair/fellow*+ACC'
[ʤɑdɯ]	'*witch*'	[ɑd–ɯ]	'*name*+ACC'

/u/		[u] < /I/	
[tortu]	'*sediment*'	[ʃort–u]	'*shorts*+ACC'
[boru]	'*pipe, tube*'	[ur–u]	'*tumor, cyst/gall*+ACC'
[kutu]	'*box*'	[dut–u]	'*mulberry*+ACC'
[tɑpu]	'*title deed*'	[ʤop–u]	'*billy club/stick*+ACC'
[kɑmu]	'*the public*'	[mum–u]	'*candle/wax*+ACC'
[muʃtu]	'*good news*'	[mut–u]	'*happiness*+ACC'
[turʃu]	'*pickle*'	[duʃ–u]	'*shower*+ACC'
[ordu]	'*army*'	[od–u]	'*room*+ACC'
[kumru]	'*dove*'	[spor–u]	'*sport*+ACC'
[nɑmlu]	'*barrel/blade*'	[pul–u]	'*stamp*'

/y/		[y] < /I/	
[stɑty]	'*status/statute*'	[syt–y]	'*milk*+ACC'
[myfty]	'*mufti*'	[ʒyt–y]	'*jute*+ACC'

[meny]	‘*menu*’	[yn–y]	‘*voice/sound*+ACC’
[ɑky]	‘*car battery*’	[dyk–y]	‘*duke*’
[byjy]	‘*magic*, *spell*’	[tyy–y]	‘*feather/fuzz*+ACC’
[dyrzy]	‘*scoundrel*’	[ʤyz–y]	‘*part*+ACC’
[kyrsy]	‘*podium*’	[sys–y]	‘*ornament*+ACC
[øʤy]	‘*boogeyman*’	[gyc–y]	‘*power*+ACC’
[kysky]	‘*doubt*’	[køk–y]	‘*root*+ACC’

/ɑ/		[ɑ] < /A/	
[birɑ]	‘*beer*’	[bɑr–ɑ]	‘*bar*+DAT’
[ojɑ]	‘*embroidery*’	[ɑj–ɑ]	‘*month*+DAT’
[kɯjɑ]	‘*murder*’	[tɑj–ɑ]	‘*one of a pair/mate*+DAT’
[pɑrɑ]	‘*money*’	[kɑr–ɑ]	‘*snow*+DAT’
[deltɑ]	‘*delta*’	[pɑrk–tɑ]	‘*park*+LOC’
[temɑ]	‘*theme*’	[ʧɑm–ɑ]	‘*pine (tree)*+DAT’
[sunɑ]	‘*drake*’	[kɑn–ɑ]	‘*blood*+DAT’
[gɯptɑ]	‘*envy without malice*’	[ɑt–ɑ]	‘*horse*+DAT’
[mɑndɑ]	‘*water buffalo*’	[cɑn–dɑ]	‘*soul/life*+LOC’
[ɯrɑ]	‘*character, nature*’	[sɯr–ɑ]	‘*glaze*+DAT’

/e/		[e] < /A/	
[dede]	‘*grandfather*’	[ev–de]	‘*house*+LOC’
[neʃe]	‘*joy*’	[beʃ–e]	‘*five*+DAT’
[kɑle]	‘*fortress*’	[dil–e]	‘*tongue/language*+DAT’
[nine]	‘*grandmother*’	[bin–e]	‘*thousand*+DAT’
[dize]	‘*line (of poetry*’	[biz–e]	‘*awl*+DAT’/’*we*+DAT’
[pyre]	‘*puree*’	[bir–e]	‘*one*+DAT’
[meme]	‘*breast/udder*’	[dem–e]	‘*breath/moment*+DAT’
[uhde]	‘*responsibility*’	[bel–de]	‘*waist*+LOC’
[meʃe]	‘*oak*’	[eş–e]	‘*spouse*+DAT’
[giʃe]	‘*cashier’s desk*’	[diş–e]	‘*tooth*+DAT’

6.2. Part 2

/Dɑ/

- [dɑ]
  - Preceding closed syllable:

[tɑbur–dɑ]	‘*battalion*+LOC’
[kur–dɑ]	‘*rate of exchange*+LOC’
[kɑjɯn–dɑ]	‘*brother–in–law*+LOC’
[kɯz–dɑ]	‘*daughter/girl*+LOC’

  - Preceding open syllable:

[kutu–dɑ]	‘*box*+LOC’
[su–dɑ]	‘*water*+LOC’
[sɑjɯ–dɑ]	‘*number*+LOC’
[tɯː–dɑ]	‘*hooked needle/awl*+LOC’

- [e]
    - Preceding closed syllable:

[yzym–de] ‘*grape*+LOC’
[gym–de] ‘*a boom, bang*+LOC’
[zejtin–de] ‘*olive*+LOC’
[pim–de] ‘*pin*+LOC’

- Preceding open syllable:

[meny–de] ‘*menu*+LOC’
[myfty–de] ‘*mufti*+LOC’
[ʤɑmi–de] ‘*mosque*+LOC’
[gemi–de] ‘*ship*+LOC’

/I/

- [i]
    - Preceding closed syllable:

[ʧift–i] ‘*pair*+ACC’
[ʤilt–i] ‘*skin*+ACC’
[semt–i] ‘*neighborhood*+ACC’
[kent–i] ‘*city*+ACC’

- Preceding open syllable:

[bin–i] ‘*thousand*+ACC’
[tim–i] ‘*team*+ACC’
[ket–i] ‘*obstacle*+ACC’
[dem–i] ‘*breath/moment*+ACC’

- [u]
    - Preceding closed syllable:

[kurd–u] ‘*wolf*+ACC’
[hurʤ–u] ‘*long bag*+ACC’
[borʤ–u] ‘*debt*+ACC’
[ʃort–u] ‘*shorts*+ACC’

- Preceding open syllable:

[put–u] ‘*idol*+ACC’
[sud–u] ‘*soda*+ACC’
[sos–u] ‘*sauce*+ACC’
[ʃok–u] ‘*shock*+ACC’

- [ɯ]
    - Preceding closed syllɑble:

[hɯrs–ɯ] ‘*desire, ambition*+ACC’
[sɯrt–ɯ] ‘*back*+ACC’
[gɑrk–ɯ] ‘*drowning*+ACC’
[ɑrz–ɯ] ‘*the earth*+ACC’

- Preceding open syllɑble:

[kɯz–ɯ] ‘*daughter/girl*+ACC’
[tɯk–ɯ] ‘*tap*+ACC’
[tɑk–ɯ] ‘*arch*+ACC’
[zɑt–ɯ] ‘*person*+ACC’

- [y]
  - Preceding closed syllɑble:

[gyrz–y] ‘*mace*+ACC’
[kyrk–y] ‘*fur*+ACC’
[ørs–y] ‘*anvil*+ACC’
[sørf–y] ‘*surfing*+ACC’

  - Preceding open syllɑble:

[tys–y] ‘*fuzz*+ACC’
[jyz–y] ‘*face*+ACC’
[gøz–y] ‘*eye*+ACC’
[søz–y] ‘*remark, utterance*+ACC’

7. Appendix C: Participant Questionnaire

1. What region of Turkey are you from?
2. What other languages do you speak?
3. Are you a native speaker of any of these languages?
4. How long have you been living in the United States?