Hacettepe University Graduate School of Social Sciences

Department of English Linguistics

THE VOWEL TRIANGLE OF TURKISH AND PHONOLOGICAL PROCESSES OF LAXING AND FRONTING IN TURKISH

Göktuğ BÖRTLÜ

Master's Thesis

Ankara, 2020

Hacettepe University Graduate School of Social Sciences

Department of English Linguistics

THE VOWEL TRIANGLE OF TURKISH AND PHONOLOGICAL PROCESSES OF LAXING AND FRONTING IN TURKISH

Göktuğ BÖRTLÜ

Master's Thesis

Ankara, 2020

ACKNOWLEDGEMENTS

I would like to express my great appreciation to my dear supervisor Dr. Zeynep Doyuran who always provided guidance and patiently answered all my questions throughout this study. She consistently allowed this study to be my own work and pointed me in the right direction even when I thought that I was fighting a desperate battle. I am also grateful to the members of the committee, Prof. Arif Sarıçoban, Assoc. Prof. Emine Yarar and Dr. Taylan Akal for their valuable feedback. Further, I would like to thank Dr. İpek Pınar Uzun and Dr. Emre Yağlı who welcomed my ideas and discussed the study with me for hours at their own offices. I appreciate them tirelessly responding to all my concerns.

My sincere thanks also go to Professor Emeritus David Odden who was strongly supportive of my desire to form phonological rules. He cared deeply about my thesis and always gave me constructive feedback. I also express my warm thanks to Professor Bruce Hayes who provided invaluable advice and improved my points. I feel extremely lucky to have been able to exchange ideas with the people whose books ignited my affection for phonology.

I am also grateful and deeply indebted to Assoc. Prof. Ayça Gelgeç Bakacak, Res. Asst. Buse Şen Erdoğan and Res. Asst. Esin Özge Esen who invested a great deal of time and effort into ensuring the smooth process of my thesis.

My special gratitude goes to Ali Karasulu who helped me with the technical details in the recordings. I would also like to thank my longtime friend Berkehan Özoğul who lent a helping hand and taught me the intricacies of RStudio while sacrificing his own valuable time.

Last but not least, I would like to express my sincere gratitude and offer my apologies to my partner, Sema, who probably had to forget the fact that I even existed from time to time. However, she still supported me every step of the way.

Thanks for all your encouragement.

ÖZET

BÖRTLÜ, Göktuğ. *Türkçenin ünlü üçgeni ve Türkçedeki sesbilimsel gevşeme ve önleşme süreçleri*, Yüksek Lisans Tezi, Ankara, 2020.

Bu tezin dayanak noktalarından biri, akustik gerçekliği yansıtan evrensel bir ünlü şemasına duyulan ihtiyaçtır. IPA tablosunda temsil edilen ünlü dörtgeni, ünlü alanını akustik sesbilgisi yönünden doğruyu yansıtmamaktadır. Lindsey (2017) IPA tablosuna bir alternatif olarak ses temelli bir ünlü üçgeni önermektedir. Türkçenin ünlü üçgeninin, Lindsey (2017) tarafından öne sürülen alternatif ünlü tablosu ile aynı doğrultuda olan, belli bir dile ait ilk ünlü tablosu olması hedeflenmiştir. Çalışma için içlerinde 12 sesbirimciğin sekizer kez geçtiği 51 kelime belirlendi. Toplamda 96 (12 x 8) ünlü sesbirimciğine sahip bu kelimeler, PowerPoint slaytlarında kısa tanımlarıyla beraber katılımcılara gösterildi. Ünlülerin F_1 ve F_2 değerleri PRAAT yardımıyla hesaplandı. Konuşucuların ünlülerinin F_1 ve F_2 değerlerinin genel ortalamaları üzerinde Lobanov (1971) normalizasyon yöntemi kullanıldı. Bu değerlere dayanılarak, Türkçenin ünlü üçgeni ortaya koyuldu.

Türkçedeki ünlüler birçok farklı çalışmada incelenmiştir (Coşkun, 2008; Ergenç & Uzun, 2017; Selen, 1979; Demircan, 2009; Erguvanlı-Taylan, 2015). Fakat, Türkçedeki ünlülerin sesbirimcikleri ve sesbirimleri henüz kapsamlı bir biçimde açıklanmamıştır. Sözü edilen ünlülerin sesbirimcikleri ve sesbirimlerine ilişkin sesbilimsel süreçler bu tezde takdim edilmiştir. Bunun yanında bu çalışma, söz konusu sesbilimsel süreçleri ortaya çıkaran kuralları da kapsamaya çalışmaktadır. Türkçede ünlüleri ilgilendiren en az iki sesbilimsel süreç bulunduğu düşünülmektedir. Bunlar önleşme ve gevşemedir. Bu çalışmada ünlü önleşmesi için bir kural ve gevşeme için dört kural ortaya atılmıştır. Bu kurallar yardımıyla, ölçünlü Türkçedeki ünlü sesbirimcikleri ve sesbirimleri arasında gözlemlenen sesbilimsel ilişkiler açıklığa kavuşturulmuştur.

Anahtar Sözcükler

Ünlü üçgeni, akustik sesbilgisi, sesbilimsel süreçler, Türkçenin ünlüleri.

ABSTRACT

BÖRTLÜ, Göktuğ. *The vowel triangle of Turkish and phonological processes of laxing and fronting in Turkish*, Master's Thesis, Ankara, 2020.

One of the motives for this thesis is the need for a universal vowel chart based on acoustic fact. The vowel quadrilateral represented in the IPA chart distorts the vowel space in terms of acoustic phonetics. Lindsey (2017) proposes a sound-based vowel triangle as an alternative to the IPA chart. The vowel triangle of Turkish is meant to be the first language-specific vowel chart in line with the alternative vowel chart of Lindsey (2017). 51 words, in which 12 allophones occur 8 times each, were selected for the study. These words containing a total of 96 (12 x 8) vowel allophones were presented to the participants with short definitions in PowerPoint slides. F_1 and F_2 values of the vowels were calculated with the help of PRAAT. The Lobanov (1971) method of normalization was employed on the overall means of F_1 and F_2 of the vowels of the speakers. Based on these values, the vowel triangle of Turkish is demonstrated.

Turkish vowels have been examined in different bodies of work (Coşkun, 2008; Ergenç & Uzun, 2017; Selen, 1979; Demircan, 2009; Erguvanlı-Taylan, 2015). Nevertheless, vowel allophones and phonemes in Turkish have not been comprehensively explained yet. The phonological processes regarding these vowel allophones and phonemes are introduced in this thesis. In addition, this study attempts to cover the rules outputting these phonological processes. Turkish seems to possess at least two phonological processes regarding vowels, namely fronting and laxing. This study puts forward one rule for vowel fronting and four rules for laxing. With the help of these rules, the phonological relations observed between the vowel allophones and phonemes of standard Turkish are clarified.

Keywords

Vowel triangle, acoustic phonetics, phonological processes, Turkish vowels.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND TO THE STUDY

According to the *Handbook of the International Phonetic Association* (1999), the idea of creating a set of symbols to cope with diverse sounds found in the languages of the world has been the main concern of the International Phonetic Association since its foundation in 1886. The first standardized IPA chart for all languages was published in 1888 ("Aur alfəbits," 1888). It has undergone many revisions since and the chart is now considered as a landmark in representing the phonetic transcription of the languages in the world. The endeavor to provide an international system for all the oral languages is very noble and the IPA has achieved this to a great extent. However, the vowel quadrilateral of the IPA is tongue-based and phonetically misrepresents the vowel space. Acoustic evidence suggests that the vowel space should be sound-based and shaped as a triangle (Lindsey, 2013). In that regard, the vowels of Turkish need to be documented fully and plotted as a vowel triangle.

Also, vowel allophones have not been comprehensively explained as yet. Standard Turkish appears to have at least two phonological processes concerning vowels (i.e. fronting and laxing). This study proposes one rule for vowel fronting and four rules for laxing. With these rules, the phonological relations between the vowel allophones and phonemes of standard Turkish are attempted to be clarified.

Turkish is considered to have three main dialect groups (i.e. Western, Northeastern and Eastern Anatolian Dialects) which consist of many dialect sub-groups (Karahan, 1996). As part of the Western Anatolian Dialects, modern Turkish is based upon Istanbul Dialect (or Istanbul Turkish) which is deemed standard Turkish (Campbell, 1995). More often than not, this so-called standard language has the implication that it is the correct and elite characterization of the language in question. One cannot simply claim that one dialect is better or more accurate than another; however, a standard language is needed due to various reasons such as education, dictionary usage, legal documents, pronunciation, literary texts, grammar, etc. In this study, standard Turkish term is treated as the most established and common dialect of Turkish.

1.2 STATEMENT OF THE PROBLEM

According to Lindsey (2017), the vowel quadrilateral misrepresents the vowel space in many ways. This is in line with the perspective of Wells (2009) that "the middle of the IPA chart represents an excessive enthusiasm for a non-Jonesian extension of the Cardinal Vowel scheme" and that some IPA symbols for vowels are solely the result of "a desire to label every intersection of lines on the chart, rounded and unrounded."

The International Phonetic Association promulgates a vowel chart that is traditionally shaped as a quadrilateral and acoustically unrealistic. For instance, no symbol exists for the low central unrounded vowel position although this vowel is exceptionally common in the languages of the world (Hayes, 2009). Also, the vowel quadrilateral simply ignores the lip postures. Many places on the chart can mark two different vowels with two different lip positions. The *Handbook of the International Phonetic Association* (1999) even concedes that the vowel quadrilateral should be considered as an abstraction. Lindsey (2017) proposes a triangular vowel chart motivated by the averaged formant values of Jones' and Wells' vowels in order to offer an alternative to the IPA vowel chart.

Turkish phonetics and specifically Turkish vowels for our purposes have been examined in different bodies of work (Coşkun, 2008; Ergenç & Uzun, 2017; Selen, 1979; Demircan, 2009; Erguvanlı-Taylan, 2015). However, there is no consensus on the number of vowel phonemes and allophones of Turkish, which is detailed in Section 2.8.

1.3 AIM OF THE STUDY

One of the main objectives of this thesis is to provide an acoustic measurement of the Turkish vowel system by analyzing the first two formants of the vowels. Formed by these vowels, a new triangular vowel chart that is closer to the acoustic reality is utilized here since the vowel quadrilateral represented in the IPA distorts the vowel space in terms of acoustic phonetics. In other words, an alternative vowel chart for Turkish is proposed in sympathy with the view of Lindsey (2017) who introduces a triangular reference vowel chart as an alternative to the IPA vowel chart. As rounded and unrounded vowels are articulated at different places in the vocal tract, this will be shown in the new chart unlike the IPA chart. A triangular Turkish vowel chart in this study which is motivated by these views will be the first in the field of Turkish phonetics.

Vowel phonemes and their allophones will also be examined. This study aims to be a reference in the field of Turkish phonetics and phonology by laying objective and descriptive foundations of the vowels. The Turkish vowels will be analyzed with phonological rules and processes. A correspondent symbol is to be determined for each vowel sound in order to enable a universal and easier pronunciation of the Turkish vowels for non-Turkish speakers. This study begs to differ from others in that it uses an alternative reference vowel chart which is sound-based to describe the vowels in Turkish rather than the classic vowel quadrilateral of the IPA.

1.4 RESEARCH QUESTIONS

In agreement with the themes stated above, this study tries to answer the following research questions:

RQ1. How can the phonetic inventory of Turkish vowels be represented in a way that is closer to phonetic reality of the vowel space?

RQ2. How can the Turkish vowel phonemes and allophones be expressed with phonological processes and rules?

1.5 OVERVIEW OF THE CHAPTERS

This thesis is composed of five chapters which are outlined below:

Chapter 1 introduces the study and presents the motivation behind it by providing the significance of the study and the statement of the problem. The need for a universal chart based on acoustic fact is explained briefly. The vowel triangle of Turkish is intended to be the first language-specific vowel chart in the literature to follow the idea of acoustically realistic vowel space proposed by Lindsey (2017). Also, the phonological processes regarding the vowels of Turkish are mentioned. Accordingly, the research questions and the aim of the study are formed. Lastly, the intended meaning of standard Turkish is clarified.

Chapter 2 offers the theoretical framework and the literature review for the study. In line with the research questions, the study can be claimed to have two parts: acoustic phonetic analysis and phonological processes of Turkish vowels. Therefore, the main topics concerning the study in terms of acoustic phonetics and phonology are detailed. The definition of sound is given. The source-filter theory and the perturbation theory are introduced. Spectra and spectrograms of vowels are demonstrated. As to phonological relationships, complementary, coincident, overlapping distribution and free variation are described. Moreover, phonological notation and distinctive feature theory are elucidated since they are of great importance to forming phonological rules for Turkish vowels. In addition, classifications of consonants and vowels are also presented in connection with their articulatory features. Furthermore, this chapter explores the issues that the IPA chart has and the reasons why it does not reflect acoustic fact. The alternative chart of Lindsey (2017) is explained in detail and his triangular vowel chart is given. Studies carried out on Turkish vowels are also included and it is shown that they differ greatly on the number of vowels in standard Turkish. At the end of this chapter, a table for Turkish consonants is given as they are deemed useful in understanding the phonological processes of the vowels.

Chapter 3 focuses on the methodology that is employed in the study. Firstly, it covers the pilot study and the details on the participants, data collection, data analysis and findings. The pilot study is a significant tool since it reveals any possible problems that can be encountered during the actual study. Therefore, researchers can determine the feasibility of the research design without further mishap. In this regard, contributions of the pilot study to the experiment are explained as well. The information about the participants, data collection and data analysis in the experiment are given and the reason why the Lobanov (1971) method of normalization was employed is detailed.

Chapter 4 shows the results of the study and offers the discussion of the findings under two headings: acoustic and phonological properties of Turkish vowels. In this chapter, a vowel triangle for Turkish is provided based on the findings. In addition, the vowel phonemes and allophones of Turkish are shown. The phonological processes affecting these Turkish vowels, namely vowel fronting and laxing, are presented. Both processes are explained by the phonological rules which yield surface representations.

Chapter 5 draws together the observations which emerge from the study. It presents the conclusion part where the research questions are answered according to the findings of the study. The limitations of this thesis are also given. Finally, suggestions for further studies are offered in an attempt to lead future studies to the similar topics that can be researched.

CHAPTER 2

LITERATURE REVIEW

2.1 ARTICULATORY PHONETICS

Describing how speech is produced is the concern of phonetics. Kenstowicz and Kisseberth (1979) define phonetics as "the study of the full range of vocal sounds that human beings are capable of making." Coughs, burps, whistles, hiccups and the sound one makes when blowing out a candle are included by this definition. However, *linguistic phonetics* should be restricted to sounds that human beings utilize when speaking a language (Kenstowicz & Kisseberth, 1979). Coughs, burps, etc. do not occur as speech sounds, which is the reason why they are excluded from linguistic phonetics.

2.1.1 Consonants

Although our main focus is on vowels in Turkish, understanding the nature of consonants will certainly prove useful in analyzing some transcriptions. In this section, in order to describe consonantal gestures, we will very briefly go over concepts such as the airstream mechanism, the glottal state, place of articulation and manner of articulation, respectively.

2.1.1.1 The Airstream Mechanism

Speech sounds are mostly the result of movements of the lips and the tongue. One can impart information by gesturing with their hands, but humans have found an astonishing way to convey meaning, that is, producing speech. Therefore, information is conveyed not just with gestures of the hands that people can see, but also with the gestures of the tongue and the lips that people can hear.

Basically, most of the world's speech gestures are initiated by pushing air out of the lungs while producing a noise in the throat or mouth and these rather basic gestures are subject to change by the movements of the lips and the tongue (Ladefoged & Johnson, 2010). This is called **egressive pulmonic airstream**. When the airstream flows inward through the nose or the mouth, this process is called **ingressive pulmonic airstream**. If the closed glottis moves upwards, it forces the air out of the mouth and sounds made this way are called

egressive glottalic airstream (i.e. ejectives) whereas sounds made with a downward movement of the closed glottis are part of **ingressive glottalic airstream** (i.e. implosives). Movement of the body of air in the mouth is called velaric airstream. Stop sounds produced with the tongue sucking air into the mouth, namely clicks, are made with an **ingressive velaric airstream**. According to Ladefoged and Johnson (2010), "it is also possible to use this mechanism to cause the airstream to flow outward by raising the tongue and squeezing the contained body of air, but this latter possibility is not actually used in any known language."

When one talks, air coming from the lungs goes up the trachea into the larynx, then passes between the vocal folds which are two small folds of tissue. The muscles of the vocal folds in the glottis may behave in different fashions, the effect of which is called the **phonation process**. These muscles can be narrowed such that the air from the lungs will set them vibrating. The sounds produced in that manner are said to be **voiced**. When the vocal folds are apart and the air is pushed through them freely, a **voiceless** sound occurs. The air passages above the larynx are the **vocal tract**. The parts of the vocal tract such as the lips and the tongue can be used to generate sounds. These parts are called **articulators**. The vocal tract consists of three cavities: the **oral cavity**, the **nasal cavity** and the **pharyngeal cavity**. The **oro-nasal process** determines what happens to the air in these cavities.

To sum up, the speech production mechanism has four fundamental elements, namely the phonation process, the oro-nasal process, the articulatory process and the airstream process. The actions of the vocal folds are named the phonation process. Whether the airstream goes out through the mouth or the nose is part of the oro-nasal process. The interaction of the tongue and the lips with the palate and the pharynx is considered as the articulatory process. The source of air is determined by the airstream process.

2.1.1.2 The Glottal State

Ladefoged and Maddieson (1996) state that the laryngeal setting has some variations which "have been used inconsistently by different authors" and admit the fact that they are included in this list as well. Consequently, it would be of use to us if the states of the glottis are to be clarified in this section. As **voiceless** and **voiced modes** exist in most of the languages, we can begin providing definitions of them. If we massively simplify the structure of the larynx, voiceless sounds are produced with the arytenoid cartilages and the ligamental folds wide open to allow the airflow through them. Thus, we observe no vibration of the vocal folds as they are pulled apart. A voiced sound involves closure along nearly the entire length of the vocal folds.

> Voicing is produced by a regular vibration of the vocal folds, the result of an aerodynamic process known as the Bernoulli effect. The vocal folds are brought together, nearly touching along their entire length. The airstream flowing between them creates a suction that draws them together, rather in the way that the air flowing over an airplane wing creates a negative pressure above the wing resulting in a lift. Once the folds come together, the suction ceases and they are forced apart by the pressure beneath them. Once apart, the suction reappears, and so the cycle is repeated. (Jensen, 2004, p. 9)

The difference between a voiced and a voiceless sound can be easily recognized by putting your hand gently over your throat. You should feel a vibration coming from the vocal folds when you say [z], which is a voiced sound, whereas no vibration indicates that it is voiceless as in the case of pronouncing the voiceless counterpart [s].

There is no dependency between the state of the glottis and place of articulation. However, we can draw a connection between the glottal state and manner of articulation, e.g. sonorants, vowels and approximants are almost always voiced. If they are devoiced under some circumstances, we need to put a diacritic (sort of an empty ring) below the sound symbol in order to indicate that, e.g. [u̥]. Voiceless obstruents are more frequently encountered than voiced ones. According to Jensen (2004), the reason for this fact is “it is difficult to maintain the airflow needed for voicing while making a major obstruction in the airstream.” One can find many languages contrasting voiceless obstruents with voiced ones, e.g. Turkish, English, Ewe, etc. Therefore, instead of using diacritics, we represent voiced and voiceless obstruents with separate symbols such as [t] and [d].

In **whisper mode**, the ligamental folds are closed while the arytenoid cartilages are open. **Breathy voice**, which is also called **murmur**, may be deemed as a combination of two glottal states: voiced and whisper mode. It involves the vocal folds vibrating and the arytenoid cartilages held slightly open as in whisper mode. Breathy voice is not a contrasting feature in Turkish or English but can be seen in some stops in Indo-Aryan languages such as Marathi and Hindi (Ladefoged & Maddieson, 1996). **Creaky voice**, also called **laryngealization**, is the term used for "sounds in which the vocal folds are held more tightly together than in regular voicing" (Ladefoged, 2001). As the vocal folds are tensed tightly, it allows slow vibration at a low airflow rate.

The pronunciation of the plosives in Turkish words such as *bas* "bass" and *pas* "rust" differs in that the latter shows a moment of voicelessness taking place after the plosive articulation and before the start of the voicing for the vowel. This period of voicelessness is called **aspiration**.

2.1.1.3 Place of Articulation

Distinguishing **passive** and **active articulators** is fruitful if we wish to describe the place of articulation of consonants. When two active articulators come together, an obstruction occurs, which results in a consonant. Typically, one is mobile (the active articulator) and the other stationary (the passive articulator). The active articulators are the lower lip and the tongue while the passive articulators consist of "the more stationary parts of the mouth and pharynx, from the lips to the glottis, with reference to which the active articulators move" (Jensen, 2004). In other words, an active articulator moves to a passive articulator which is generally sufficient to state the place of articulation of a sound. Therefore, if we describe the place of articulation a consonant as **alveolar**, then we understand that the passive articulator is the alveolar ridge. The tongue makes contact with the alveolar ridge in this case. We can also specify the active articulator with a prefix. For instance, **apico-alveolar** demonstrates that the active articulator is the tip of the tongue. **Lamino-alveolar**, likewise, indicates that the air passage is obstructed by the blade of the tongue (i.e. the part just behind the tip) which is the active articulator (Brosnahan & Malmberg, 1970).

Bilabial sounds are produced with the two lips coming together, e.g. /b/, /m/ and /p/. **Labiodental** sounds, e.g. /f/ and /v/, are articulated with the lower lip raised until it (almost) touches the upper teeth. **Dental** consonants are made with the tongue against the upper teeth such as /θ/, /ð/ which are also called **interdental** sounds. Dental sounds are conventionally symbolized with a diacritic, e.g. /t̪/, /d̪/, /n̪/, etc. Using the blade of the tongue in the dental articulation leads to **denti-alveolar** sounds as opposed to the tip of the tongue in the alveolar ridge (Ladefoged & Maddieson, 1996). However, generally the articulation made with the tip or the blade of the tongue and the alveolar ridge is considered to generate **alveolar** sounds such as /n/, /s/, /z/, etc. A **retroflex** consonant is articulated between the alveolar ridge and the hard palate with the tip of the tongue curled up to some extent. /ɳ/, /ʈ/, /ɽ/ are some of the retroflex consonants in the International Phonetic Alphabet (IPA) chart. **Palato-alveolar** sounds, which can also be called **postalveolar**, are made with the blade of the tongue and the back of the alveolar ridge, near the forward part of the hard palate. These sounds include, but are not limited to /ʃ/, /ʒ/, /tʃ/ and /dʒ/. **Palatal** consonants are articulated with the body of the tongue raised against the hard palate. /j/ is arguably the most recognizable of the palatal sounds as it is frequently mentioned in the context of the sound change called palatalization. **Velar** sounds involve “the back of the tongue touching the soft palate (the velum)” (Ladefoged, 2001). According to Maddieson (1984), the velar stops, namely /k/ and /g/, are one of the one most common stop classes across the world’s languages, 99.4% of which have velar stops in their phonetic inventories. “Retraction of the dorsum allows the back of the tongue to articulate with the uvula” (Gussenhoven & Jacobs, 2011), in which case a **uvular** sound occurs, e.g. /q/, /ʀ/, /ɢ/, /ɴ/, etc. **Pharyngeal**/**Epiglottal** sounds are articulated with the root of the tongue pulled towards the back wall of the pharynx. Most of the pharyngeal sounds are fricatives, namely /ħ/ and /ʕ/, which can be seen in Arabic and Hebrew (Ladefoged & Maddieson, 1996). However, Catford (1983) suggests that the Chechen may have a pharyngeal stop, for which the IPA symbol is /ʡ/. These pharyngeal plosive sounds have also been observed by Laufer and Condax (1981) who hold that they are the allophones of the pharyngeal fricatives in Semitic languages. **Glottal** consonants are those produced with the glottis as their primary articulation point. We can give /h/ and /ʔ/ as examples for glottal sounds.

2.1.1.4 Manner of Articulation

Some articulatory gestures can be achieved at most of the places of articulation. The articulators may block the oral tract for a moment or a rather long period; they may reduce the space greatly or they may just reshape the tract by approaching one another.

In **stop** sounds, the air is completely stopped in the vocal tract. In addition to this closure in the mouth, the velum may be raised so that the air cannot go out through the nose. Then, pressure in the mouth will increase and an **oral stop** will be produced. However, along with the closure in the vocal tract, if the soft palate is lowered so that the air *can* go through the nose this time, then a **nasal** stop will be produced. In **fricative** consonants, the air escapes through a narrow gap and creates a hissing noise (Roach, 2009). Fricatives are so-called continuant sounds, which means one can continue producing them as long as their lungs allow them to. An **affricate** begins with a stop and ends with a fricative, combining the two sounds. This combination is also represented in affricates' IPA symbols as in [tʃ] and [dʒ]. In an **approximant**, the active articulator (i.e. the lower lip or the tongue) narrows the vocal tract, but not so much that the articulators cause a hissing sound that is the sign of a fricative. Therefore, approximants fall between two boundaries: vowels, with no constriction, and fricatives, whose constriction produces a turbulent nose (Martínez-Celdrán, 2004).

In the field of phonology, consonants can also be categorized into two extensive classes with regard to their manner of articulation: *sonorants* and *obstruents* (Jensen, 2004). Stops, fricatives and affricates are included in the latter group since, by definition, obstruents are made by obstructing airflow, thus some pressure is built up in the vocal tract. In producing sonorants, on the other hand, air flows freely and no pressure is observed in the vocal tract. These include the flaps, laterals, nasals, trills, glides and vowels. They are commonly accompanied by voicing at the vocal folds. For instance, the nasals (e.g. /n/ and /m/) have the same place of articulation as the corresponding plosives (e.g. /d/ and /b/), but the articulation of the nasals causes the velum to move down so that the air comes out through the nose (Ladefoged, 2001). In [+continuant] sounds, the airflow passes through the mouth while [-continuant] sounds are made with an occlusion in the vocal tract. Therefore, oral stops, affricates and nasals are [-continuant] due to their closure in the oral cavity.

2.1.2 Vowels

2.1.2.1 Vowel Classification

It is probably not an overgeneralization to claim that almost everyone knows how a vowel sounds, but when it comes to describing vowels, it is hardly an easy task. Vowels are defined using different terminology from consonants as the articulators are far enough apart, allowing no constriction in their production. In other words, the manner of articulation classifications that are used for consonants are not appropriate for vowels. Moreover, vowels are articulated in a more limited area of the vocal tract than consonants, that is, consonantal places of articulation are not appropriate, either. In addition, given that vowels are considered sonorants, they are typically voiced (see Section 2.1.1.4). For this reason, in describing vowels, we do not generally use the voice feature which is of great importance for consonants. Nevertheless, voiceless vowels have been documented to have a certain phonological role in Ik (Davenport & Hannahs, 2005; Heine, 1975) and Dafla (Ray, 1967).

Vowels can be classified into three aspects: **height**, **backness** and **rounding**. Vowel height is determined by the height of the tongue, that is, the higher the tongue, the higher the vowel. Vowels are also categorized horizontally as front, central or back regarding which part of the tongue is in the highest position. The third classification, rounding, is very much influenced by the position of the lips. The basic binary parameters formed with respect to these three aspects are called high and low, front and back, and rounded and unrounded.

2.1.2.2 The Primary Cardinal Vowels

The IPA symbols for vowels are traditionally arranged on a quadrilateral in which corners describe extreme vowel positions. Figure 1 shows the four extreme articulation possibilities for vowels, namely the high front, high back, low front and low back positions ([i], [u], [a] and [ɑ] respectively).

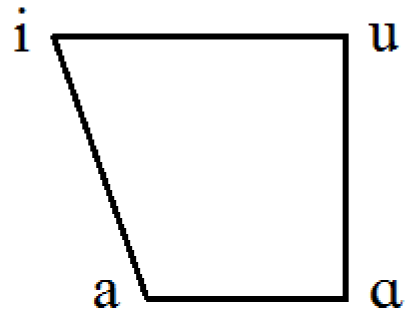


Figure 1. Extreme vowel positions in the IPA.

"The high front vowel [i] is the highest possible front vowel; any further raising of the tongue would result in a fricative sound. The low back vowel [ɑ] is the lowest possible back vowel; further retraction of the tongue would result in a pharyngeal fricative" (Jensen, 2004, p. 13). Jensen (2004) also designates [æ] for the low front unrounded vowel ([a] in Figure 1) in the context of extreme positions of vowels although we find that [a] exists in Turkish as an allophone of [ɑ] (see Section 4.1.2.2). *The Principles of the International Phonetic Association* (1949) notes the same problem with these symbols and claims that treating [a] and [ɑ] as symbols denoting different sounds has proved unsuccessful. However, accepting the fact that they are two separate sounds yields beneficial effects as part of allophonic relations in Turkish vowels.

Daniel Jones (1966) devised a cardinal vowel scheme in which these extreme positions are represented with the addition of four more vowels, i.e. [e], [ɛ], [o] and [ɔ] as shown in Table 1.

Table 1. Primary cardinal vowels.

	front	back
high	i	u
higher mid	e	o
lower mid	ɛ	ɔ
low	a	ɑ

According to Table 1, the primary cardinal vowels are grouped under two qualities of backness (i.e. front and back) and three of height (i.e. high, mid and low) while the mid region may be further split into higher mid and lower mid. [u], [o] and [ɔ] are rounded but all the other cardinal vowels are unrounded.

2.1.2.3 The Secondary Cardinal Vowels

The secondary cardinals are achieved by reversing the lip postures of the primary cardinal vowels. For instance, if we reverse the lip posture of the high back rounded vowel [u] in Table 1, we get [ɯ], which is unrounded. In short, the secondary cardinals are considered to be at the same articulation place as the primary cardinals, differing only in lip rounding (Davenport & Hannahs, 2005). A further pair of central vowels, [ɨ] and [ʉ], are added to the secondary cardinal vowels list. This gives a total of 18 cardinal vowels, with eight being primary and ten secondary. The occurrence of secondary cardinal vowels is claimed to be less common than that of the primary cardinals (Ladefoged & Maddieson, 1996). All the cardinal vowels, with the addition of the secondary cardinals, are showed in Table 2.

Table 2. The cardinal vowels (primary and secondary).

	front	back	front	back	central	
high	i	u	y	ɯ	ɨ	ʉ
high-mid	e	o	ø	ɤ		
low-mid	ɛ	ɔ	œ	ʌ		
low	a	ɑ	ɶ	ɒ		

Figure 2 is a vowel quadrilateral of the cardinals which is very commonly used in the field. The quadrilateral should be regarded as an abstraction such that it does not directly represent the tongue position.

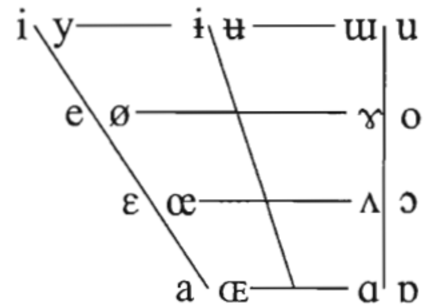


Figure 2. The vowel quadrilateral with the cardinal vowels.

2.1.2.4 The IPA Vowel Chart

The vowel chart of the IPA differs from that of the cardinals in that the former includes several central vowels and a number of vowels at intermediate locations. In addition to both the primary and secondary cardinals which lie on the outside edge of the quadrilateral, we observe [ɘ], [ɵ], [ɜ], [ɞ], [ə] and [ɐ] as central; [ɪ], [ʏ] and [ʊ] as mid-centralized from [i], [y] and [u] respectively; and [æ] at the near-low front positions. All these additional symbols are provided with their descriptions in Table 3 as well as all the cardinal vowels. In other words, Table 3 consists of all the vowels that the IPA chart offers. The unrounded vowels are conventionally placed to the left of their rounded counterparts. For instance, [i] and [y] are both high front vowels, however, they only differ in roundedness.

Table 3. The vowels of the IPA chart.

unrounded	rounded		unrounded	rounded	
i	y	high front	ə		mid central
ɨ	ʉ	high central	ɛ	œ	low-mid front
ɯ	u	high back	ɜ	ɞ	low-mid central
ɪ	ʏ	near-high front	ʌ	ɔ	low-mid back
	ʊ	near-high back	æ		near-low front
e	ø	high-mid front	ɐ		near-low central
ɘ	ɵ	high-mid central	a	ɶ	low front
ɤ	o	high-mid back	ɑ	ɒ	low back

Although Table 3 demonstrates the complete set of the IPA symbols, a traditional vowel quadrilateral is presented here as well for better visualization (see Figure 3). It should be borne in mind that this chart does not serve as a precise anatomical diagram regarding the vowel space. Put differently, the chart is an idealized adaptation of the vowel space. It is not based upon real articulatory distances between vowels, therefore being rather perceptual (Davenport & Hannahs, 2005). See Section 2.7 for more discussion on this issue.

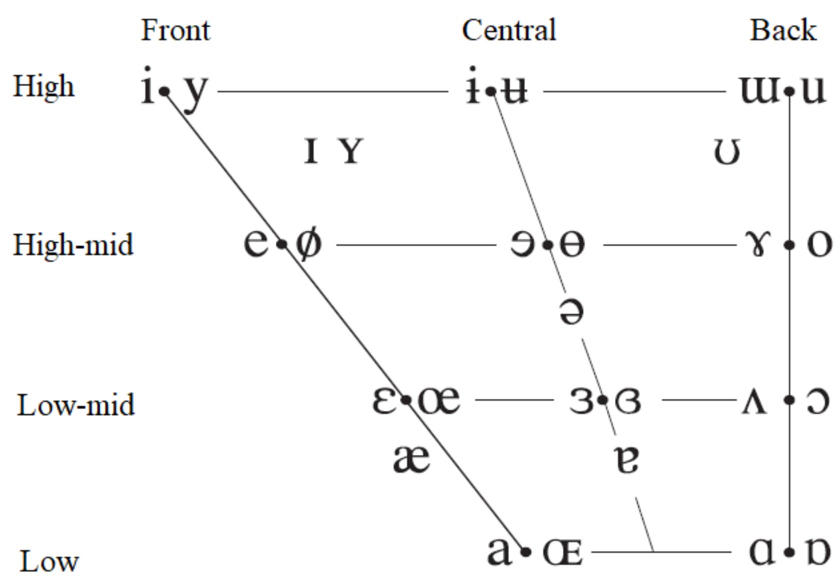


Figure 3. The IPA vowel chart.

2.1.2.5 Suprasegmentals

Consonants and vowels can be considered as the segments which speech consists of (Ladefoged & Johnson, 2010). Speech may form patterns that go beyond the linear arrangement of segments and/or change independently of segmental values. These include tone, intonation, stress and syllable structure. These properties are frequently referred to as **suprasegmentals**. The IPA provides a variety of symbols for suprasegmentals.

Syllable boundary is indicated by a period or the symbol $, e.g. [ɹi.ækt]. In a sequence of syllables, one syllable entails "more muscular effort in its production" (Davenport & Hannahs, 2005, p. 78). This syllable, which is said to bear stress, is more prominent than the others. It is likely that there will only be one stressed syllable in words of two or three syllables. Nevertheless, in longer words, we can observe that two or more syllables bearing stress (Ashby & Maidment, 2005). In that case, the most prominent syllable is called to bear the **primary stress** which is shown by a raised tick (e.g. ɹiˈækt). Other stresses in a word are named the **secondary stresses** which are marked with a lowered tick (e.g. ˌkɑːnsənˈtreɪʃən). Therefore, the IPA allows for indicating as many as three degrees of prominence; in *concentration* [ˌkɑːnsənˈtreɪʃən], the most prominent syllable is the third one and the second most prominent syllable is the first one while the remaining syllables are less prominent. The *Handbook of the International Phonetic Association* (1999) has documented that extra strong stress can be illustrated by doubling the stress mark as in [əˈˈmeɪzɪŋ].

In addition, segmental length can also be illustrated on a continuum [ĕ e eˑ eː] from short to long respectively. The *Handbook of the International Phonetic Association* (1999) further suggests that even greater length can be shown as [eːːː], for instance.

Pitch variation can be used to distinguish grammatical or lexical meaning, that is, to distinguish words, in which case it is called **tone** (Yip, 2002). Although the general opinion is that tone sounds exotic for English or Turkish speakers, up to 70% percent of the world's languages are tonal, e.g. Cantonese, Vietnamese, Yoruba and Swedish (Yip, 2002). The IPA chart presents two sets of symbols for tone, which are level and contour as shown in Figure 4.

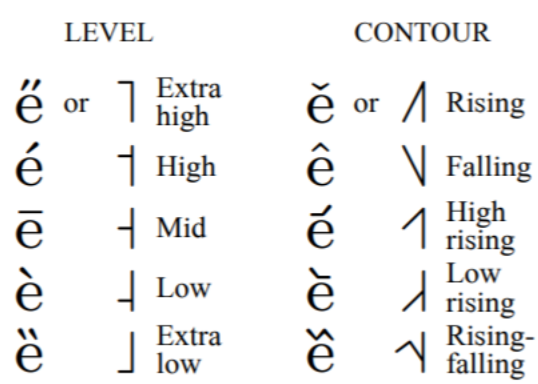


Figure 4. The IPA symbols for tone.

The use of pitch does not always impact on the meaning of words, but it may affect how utterances are interpreted and is known as **intonation** (Ashby & Maidment, 2005). This is said to be true in all languages according to the *Handbook of the International Phonetic Association* (1999), yet the intricacy of intonation may change across languages. Furthermore, Ashby and Maidment (2005) support the very same view that pitch variation is used in all languages to communicate meaning. Italian, French, German, English and Turkish may not be lexical tone languages, but they all use intonation to convey emotions, attitudes, surprise, etc. The symbol [‖] is utilized to indicate the end of an intonation pattern (intonation group) and [|] to demarcate a smaller unit (foot group).

2.1.2.6 Diacritics

A **diacritic** is a mark that modifies or refines the meaning of the symbol that it is added to. Diacritics may deal with phonation types, that is to say, they reverse the voicing value, denote aspiration, creaky voice and breathy voice. Some can be used to adjust the tongue or lip position that a vowel entails. For instance, [o̜] indicate a vowel with a less rounded lip position. Some sounds get raised or lowered with the help of diacritics. [ɹ̝] indicates an alveolar approximant that is raised such that it becomes a fricative-like sound. Rhoticity can also be demonstrated with a diacritic. For instance, [ə˞] represents a rhotacized schwa. Moreover, alveolar sounds can be modified with the dental diacritic, showing their dental articulation, e.g. [n̪]. There are also diacritics which are used to modify which part of the tongue is making an articulation, i.e. laminal (the blade) or apical (the tip). Sound changes such as palatalization, pharyngealization and velarization can be made explicit as in [tʲ tˤ tˠ] respectively. The alternative diacritic for velarization can be observed in [ɫ] which is the velarized lateral. Besides, nasalized vowels are also shown with a diacritic as in [ɛ̃] and [ɔ̃], both of which can be observed in French. Obviously, many more diacritics exist in the IPA, however, instead of stating all of them here, it is more reasonable to show them all on the chart itself with an example for each (see Figure 5).

◌̥	Voiceless	n̥ d̥	◌̤	Breathy voiced	b̤ a̤	◌̪	Dental	t̪ d̪
◌̬	Voiced	s̬ t̬	◌̰	Creaky voiced	b̰ a̰	◌̺	Apical	t̺ d̺
ʰ	Aspirated	tʰ dʰ	◌̼	Linguolabial	t̼ d̼	◌̻	Laminal	t̻ d̻
◌̹	More rounded	ɔ̹	ʷ	Labialized	tʷ dʷ	◌̃	Nasalized	ẽ
◌̜	Less rounded	ɔ̜	ʲ	Palatalized	tʲ dʲ	ⁿ	Nasal release	dⁿ
◌̟	Advanced	u̟	ˠ	Velarized	tˠ dˠ	ˡ	Lateral release	dˡ
◌̠	Retracted	e̠	ˤ	Pharyngealized	tˤ dˤ	◌̚	No audible release	d̚
◌̈	Centralized	ë	◌̴	Velarized or pharyngealized	ɫ			
◌̽	Mid-centralized	e̽	◌̝	Raised	e̝ (ɹ̝ = voiced alveolar fricative)			
◌̩	Syllabic	n̩	◌̞	Lowered	e̞ (β̞ = voiced bilabial approximant)			
◌̯	Non-syllabic	e̯	◌̘	Advanced Tongue Root	e̘			
˞	Rhoticity	ɚ a˞	◌̙	Retracted Tongue Root	e̙			

Figure 5. Diacritics in the IPA.

2.2 ACOUSTIC PHONETICS

2.2.1 What Is Sound?

Sound is defined as a pressure wave that propagates in waves from a source. Sounds can be broken down into two patterns: **periodic** and **aperiodic**. In a periodic sound, a pressure wave of a certain shape has a repeating pattern. Musical notes or vowels are included in period sounds. Figure 6 demonstrates a waveform of 50 milliseconds of the vowel [i] articulated by Daniel Jones. A waveform is a representation of pressure fluctuations over time (Johnson, 2003). Higher pressure, **compression**, is marked with positive values while lower pressure, **rarefaction**, negative values. The value 0 shows equilibrium. The repeating pattern is clear in this waveform. We cannot see perfect replicas in each circle in Figure 6 since the vowel was produced by a human being rather than a machine.

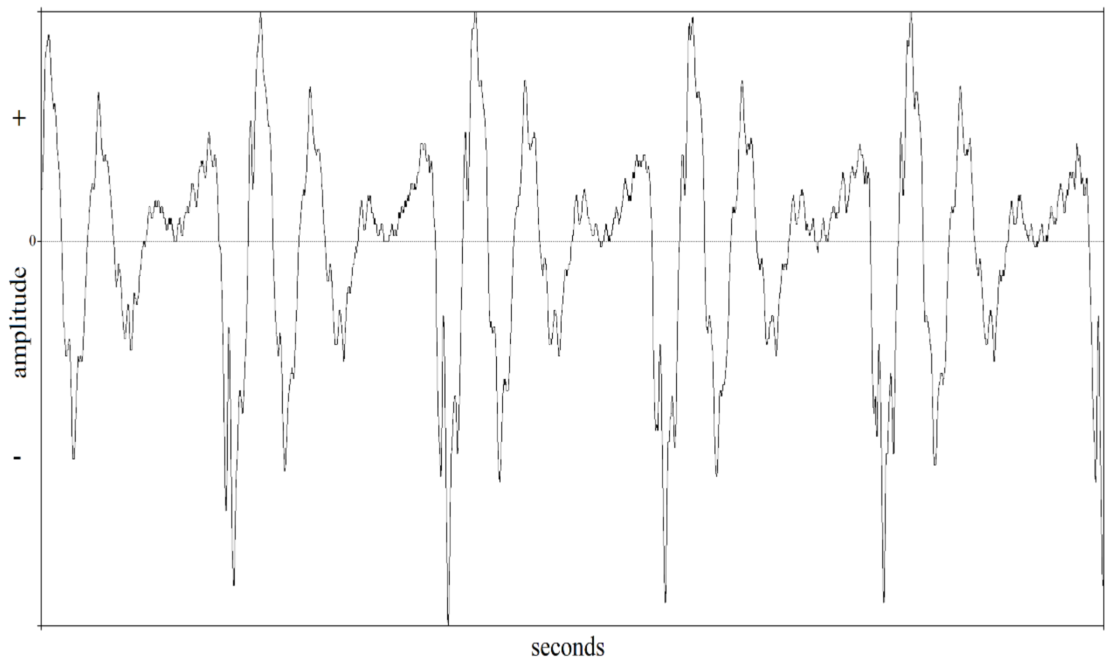


Figure 6. Waveform of the vowel [i], a periodic sound.

Aperiodic sounds do not exhibit such a regularly repeating pattern, that is, random pressure variations are more likely to occur. The rustling of leaves, radio static, the scratching of sandpaper, the sound of chicken being fried in a pan and fricatives are examples of so-called aperiodic sounds (Zsiga, 2013; Fry, 2012). Sound that is defined by such random pressure fluctuations is also named “white noise” (Johnson, 2003). Figure 7 is a waveform of 50 milliseconds of the fricative sound, namely /s/, at the beginning of the word *saat* ‘hour’. In this waveform, there is no repeating pattern to be seen.

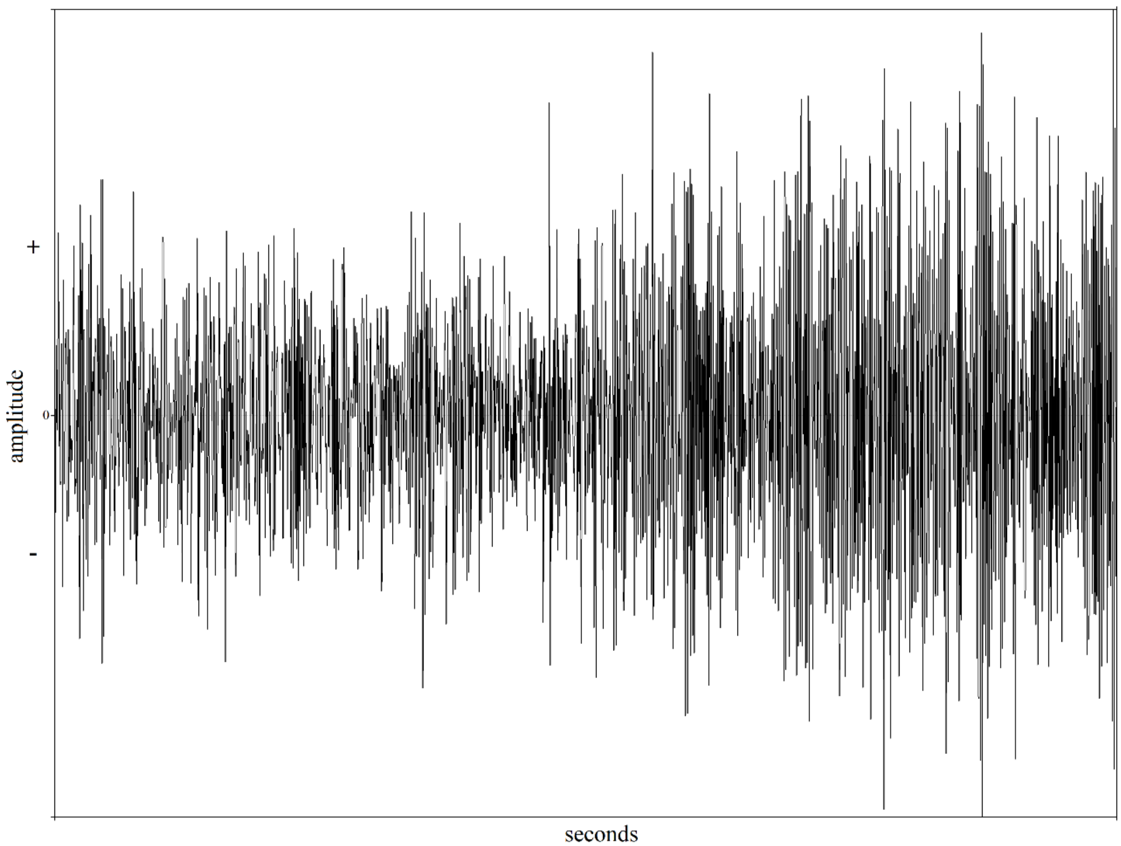


Figure 7. Waveform of the fricative /s/, an aperiodic sound.

There is another category that falls under aperiodic sounds: **transient** sounds. Transient sounds demonstrate instantaneous pressure fluctuations, e.g. door slams, the crash of breaking glass, balloon pops, etc. Figure 8 indicates 50 milliseconds of a transient sound, which is the recording of a clap of my hands. The waveform starts with silence, then an abrupt burst of noise appears, followed by silence again.

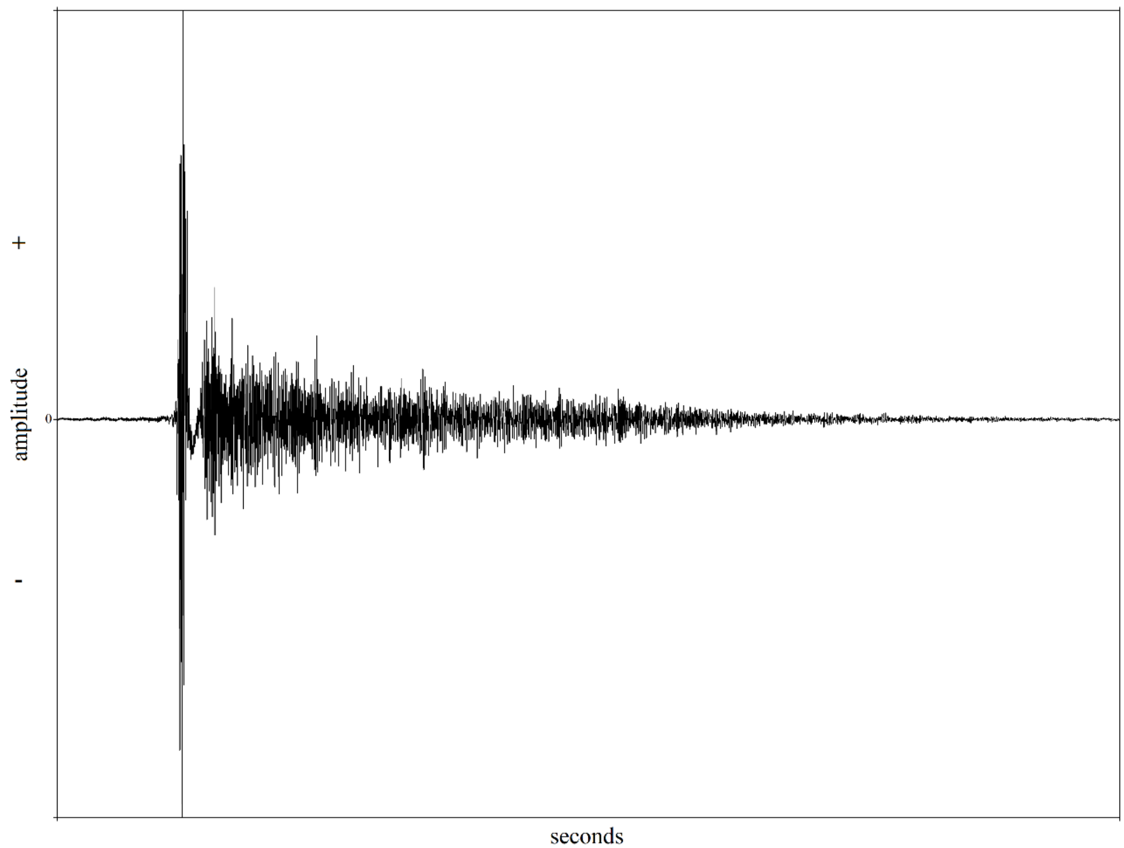


Figure 8. Waveform of a clap, a transient sound.

2.2.2 Simple Harmonic Motion

In order to grasp the nature of sound waves, we can begin with the description of the motion of a pendulum. The physics behind the motion of sounds waves and a pendulum are the same (Zsiga, 2013; Clark & Yallop, 1990). The motion of a pendulum is shown in Figure 9.

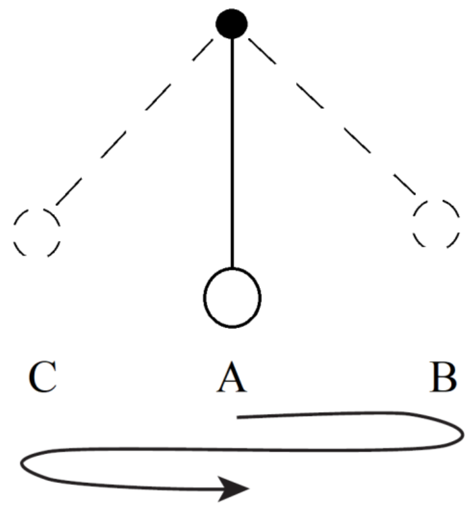


Figure 9. The motion of a pendulum.

Consider that the pendulum hangs straight down at its rest position, which is A in this case. If you push or pull up the pendulum bob to B and release it, it swings back, passes over A and reaches a maximum displacement, which is C in this case, thanks to inertia. Then, it swings back down to A. That motion represents one full cycle which repeats over and over again. Ideally, this simple system would oscillate indefinitely when set in motion. Obviously, in practice, the motion comes to an end due to air resistance and friction. Thus, we can observe the loss of energy, known as **damping**, in each cycle. The time it takes for one full cycle is termed **period**. The number of cycles per second (abbreviated *cps*) is called **frequency** (measured in *Hertz* and abbreviated *Hz*). Should this pendulum belong to a clock, the frequency of it will be 60 cycles per minute with a period of 1 second. In acoustics, this can be regarded as the most fundamental formula: F=1/P.

Figure 10 demonstrates the motion of a clock pendulum that has a period of one second. We can also see that it has peak amplitude of 10 cm. As can be seen, the pendulum completes one full cycle in one second. A second cycle is completed at time 2 and a third cycle at time 3. Figure 10 is an example of a **sinusoid**. It can also be called as a **sine wave** if and only if it starts at 0 (as in Figure 10).

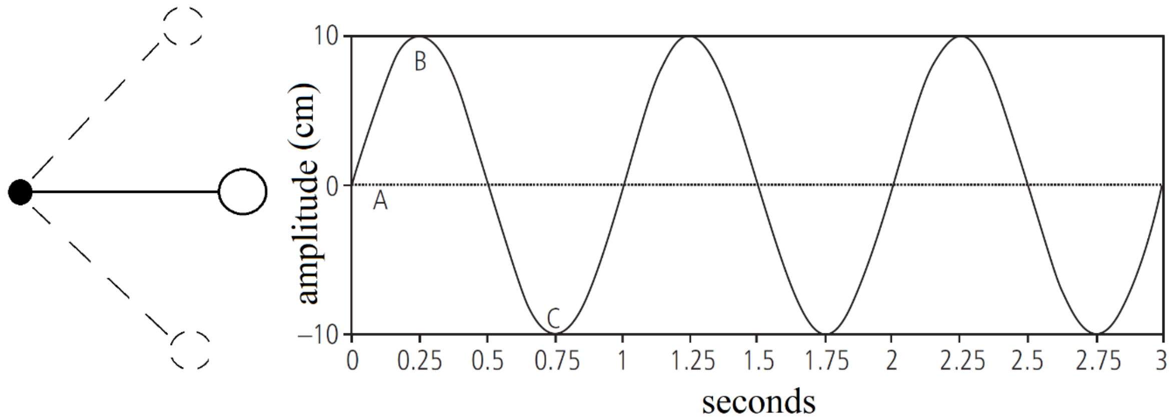


Figure 10. The motion of a pendulum (with peak amplitude of 10 cm and a period of one second).

2.2.3 Complex Waves

Although we can observe many periodic wave patterns in nature, not all of them are as straightforward as the motion of a pendulum. Complex waves are obtained by building up one such motion on another. Figure 11 shows three sinusoids with different frequencies on top of each other.

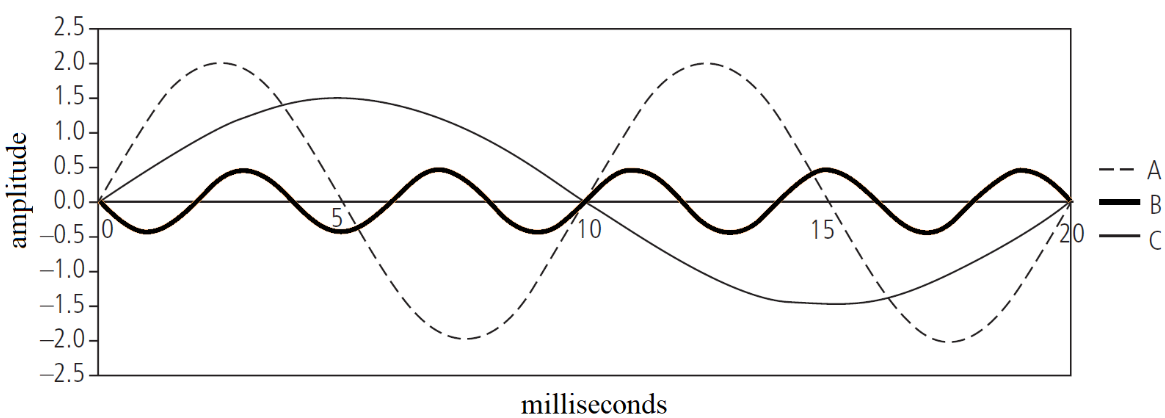


Figure 11. Three sinusoids.

It takes 10 ms (0.01 seconds) for Wave A (dashed) to complete one full cycle. Therefore, its frequency is 100 Hz (1/0.01). For Wave B (bold), on the other hand, it takes 20 ms to complete 5 cycles, so it has a period of 4 ms. That is, one cycle takes 4 ms (0.004 seconds) for Wave B. Accordingly, it has a frequency of 250 Hz (1/0.004). Wave C completes one cycle in 20 ms (0.02 seconds), thus its frequency is 50 Hz (1/0.02). Wave A seems to have a peak amplitude of 2 units, B .5 units and C 1.5 units. Frequency and amplitude are sufficient to define a sinusoid. **Spectrum** is a graph made of frequency and amplitude (see Figure 12).

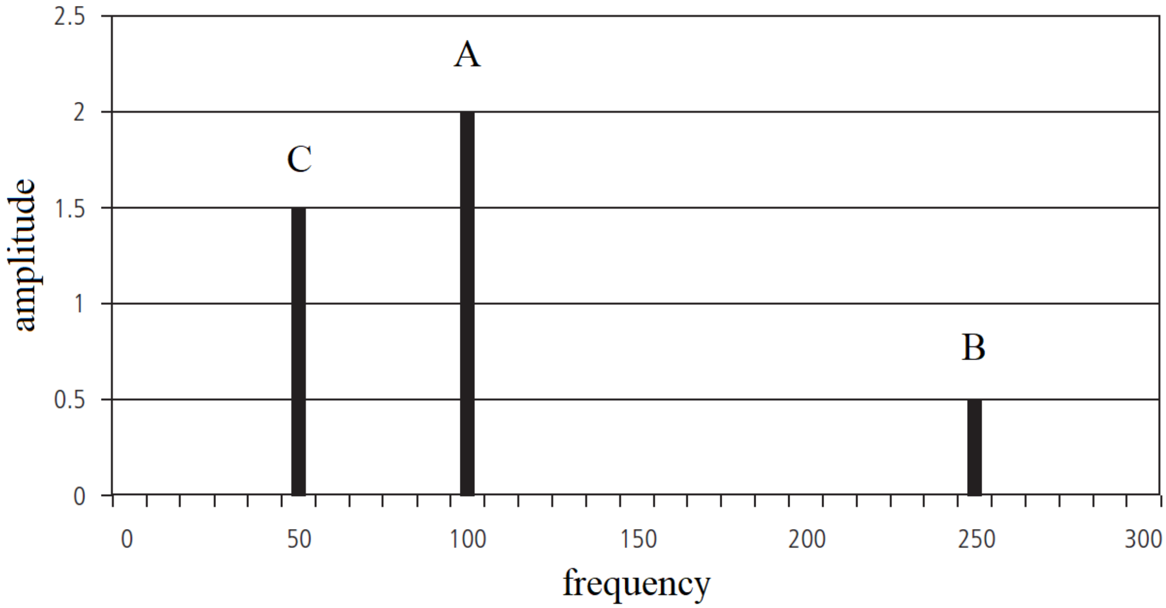


Figure 12. The spectrum of the three waves in Figure 11.

Now that we have analyzed the waves A, B and C, we can add these sinusoids and get a **complex wave** as a result. The boldest line in Figure 13 marks the sum. Every single point chosen on the boldest line equals to the sum of the three waves, namely A, B and C.

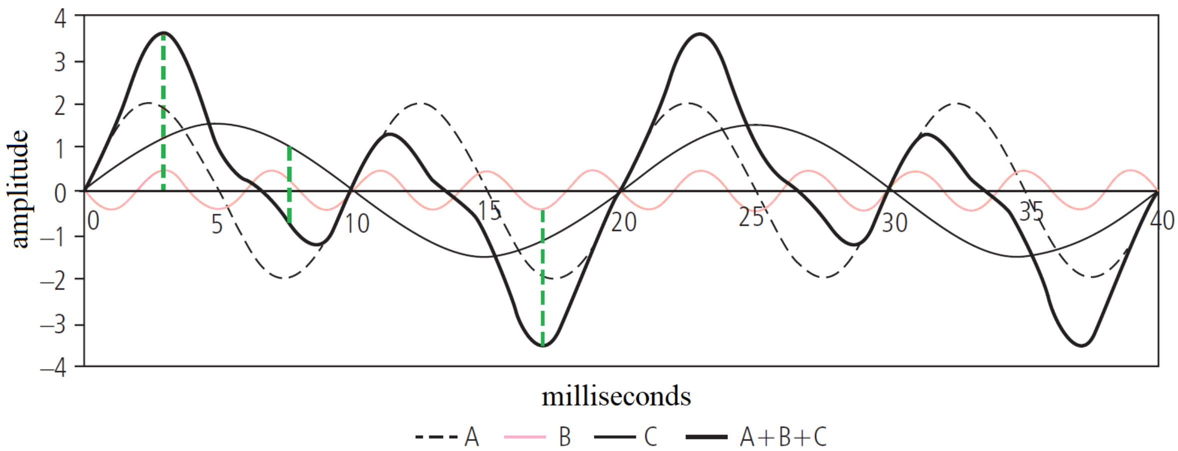


Figure 13. The sum of the three waves.

Several points of time are marked with dashed green lines in order to draw attention to the sum of the waves. For instance, at time 3 ms, A has an amplitude of +1.9 units, B +0.45 units and C +1.2 units. The sum of the three is +3.55. At 8 ms, A has an amplitude of -1.9 units, C +0.88 units while Wave B passes very close to 0. The sum at 8 ms is -1.02. At 17 ms, since all A, B and C are strongly negative, the result is strongly negative as well.

Although it is not sinusoidal, it is clear from Figure 13 that the complex wave is periodic. It has a period of 20 ms (0.02 seconds), i.e. the cycle repeats every 20 ms. The frequency of this complex wave is thus 50 Hz (1/0.02). This is called the **fundamental frequency**, abbreviated f_o and pronounced 'f-zero'. It always equals to the greatest common factor of the component frequencies of a complex wave (Zsiga, 2013). The component frequencies which can be seen in Figure 11, Figure 12 and Figure 13 are 50 Hz, 150 Hz and 250 Hz. Therefore, f_o is 50 Hz. The fundamental frequency is also what determines the pitch.

The sine wave components a complex periodic wave has are known as **harmonics**. Harmonics occur at integer multiples of f_o (Hayward, 2014). If the fundamental frequency happens to be 120 Hz, then the second harmonic is 240 Hz, the third 360, the fourth 480 and so on. If f_o of a sound is 210 Hz, then harmonics will be at 420 Hz, 630 Hz, etc.

2.2.4 The Source-Filter Theory

The contemporary understanding of the intricacies of vocal tract acoustics has been based predominantly on the source-filter model (Kent, 1993). Therefore, the acoustic properties of speech production are traditionally analyzed and interpreted thanks to the source-filter model. In light of this theory, speech production is basically considered as a two-stage process, i.e. a speech signal is generated from the sound source and modified by the vocal tract which functions as a frequency-selective filter (Clark & Yallop, 1990). Resonant frequencies of the vocal tract are amplified while others are damped out (Zsiga, 2013). These resonant frequencies are named **formants**, abbreviated F_n, where n denotes the frequency number.

The filtering effects of the vocal folds include the radiation characteristic and the formants, both of which make up the transfer function that links source energy to radiated acoustic energy. For non-nasal vowels, Kent and Kim (2008) present a simple model which can be summarized under three headings:

a) the source and the filter make separate contributions to the output sound, i.e. they are independent of each other (Kent & Kim, 2008; Hayward, 2014; Harrington & Cassidy, 1999; Stevens, Kasowski, & Fant, 1953; Fant, 1960; Stevens & House, 1963).

b) only formants take part in the transfer function.

c) radiation characteristics and source are unchanging across vowels.

However, there have been claims that source and filter, in fact, interact; they have significant implications in singing and speech (Kent, 1993; Fant, 1986). In short, for a typical vowel sound, the vibration of the vocal folds and the combined impact of the formants constitute the source and the filter, respectively.

The sound articulated at the vocal folds consists of a fundamental frequency (f_o) and harmonics of f_o. The amplitude of these harmonics is inversely proportional to the frequency of them, that is, as the frequency increases, the intensity of these harmonics is inclined to decrease as can be seen in Figure 14. If we were to listen to this sound, it would be more like a buzz, rather than a traditional speech sound.

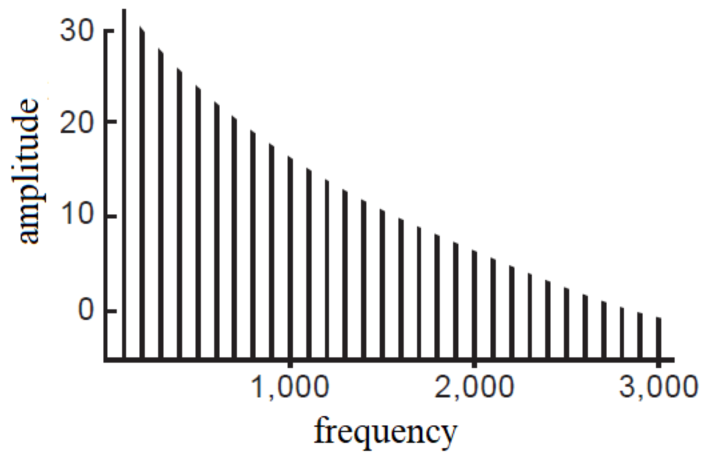


Figure 14. Glottal pulses (source function).

The resonant frequencies of a vocal tract which is 17.5 cm long are 500, 1500 and 2500 Hz as can be observed in Figure 15 (see section 2.2.5 for more detail). The sound that is produced by the glottal source is being *filtered* through this vocal tract which resonates at those frequencies. If the harmonics of the sound that is produced by the glottal pulses are near or at the resonant frequencies of the vocal tract, then these harmonics are resonated while others are attenuated.

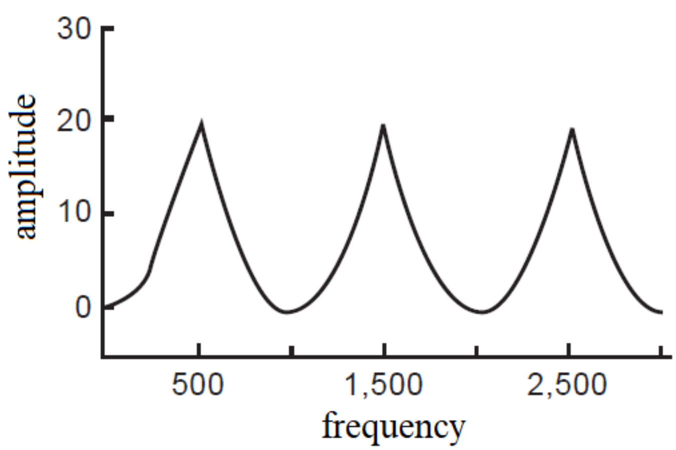


Figure 15. Resonances of a 17.5-cm-long vocal tract (transfer function).

Although the output sound of this source and transfer functions has the same harmonics as the sound produced by the glottis, the amplitudes of these harmonics change (see Figure 16). It should be kept in mind that the frequencies 500, 1500 and 2500 Hz mentioned here are relevant only for a neutrally shaped vocal tract of a male. A longer or shorter vocal tract would yield different resonant frequencies. A speaker may also alter the size of his vocal tract by moving his tongue, jaw or lips, which affects the frequencies at which the vocal tract resonates.

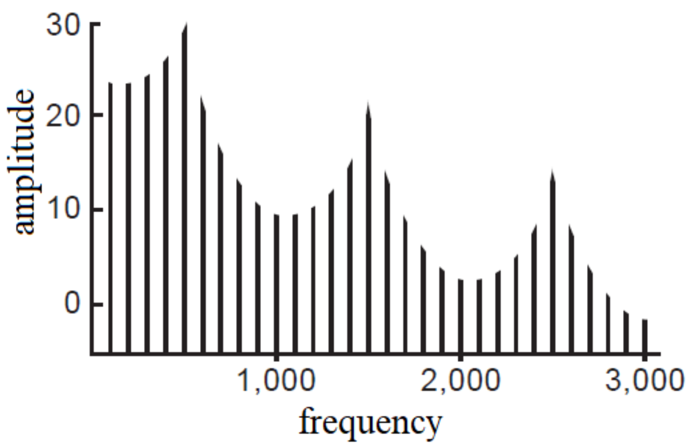


Figure 16. The output sound, the product of source and transfer functions.

2.2.5 Resonance of a Tube Open at One End

The average distribution of formant frequencies is defined by the length of the vocal tract. This can be explained with a basic acoustic model, a tube open at one end and closed at the other (Kent, 1993). During the production of a vowel, the vocal tract resembles a tube that is of uniform diameter over its length. The wavelength (λ) of the lowest frequency which such a tube resonates at is four times the tube's length. The wavelength of a tube which is 17.5 cm long (the length of the vocal tract of Peter Ladefoged, who is widely regarded as one of the pioneers in phonetics) is thus 70 cm. However, it should be borne in mind that a vocal tract that is 17.5 cm long is not the standard since the average length of the vocal tract that belongs to an adult man is 16.9 cm while it is 14.1 cm in adult females (Goldstein, 1980).

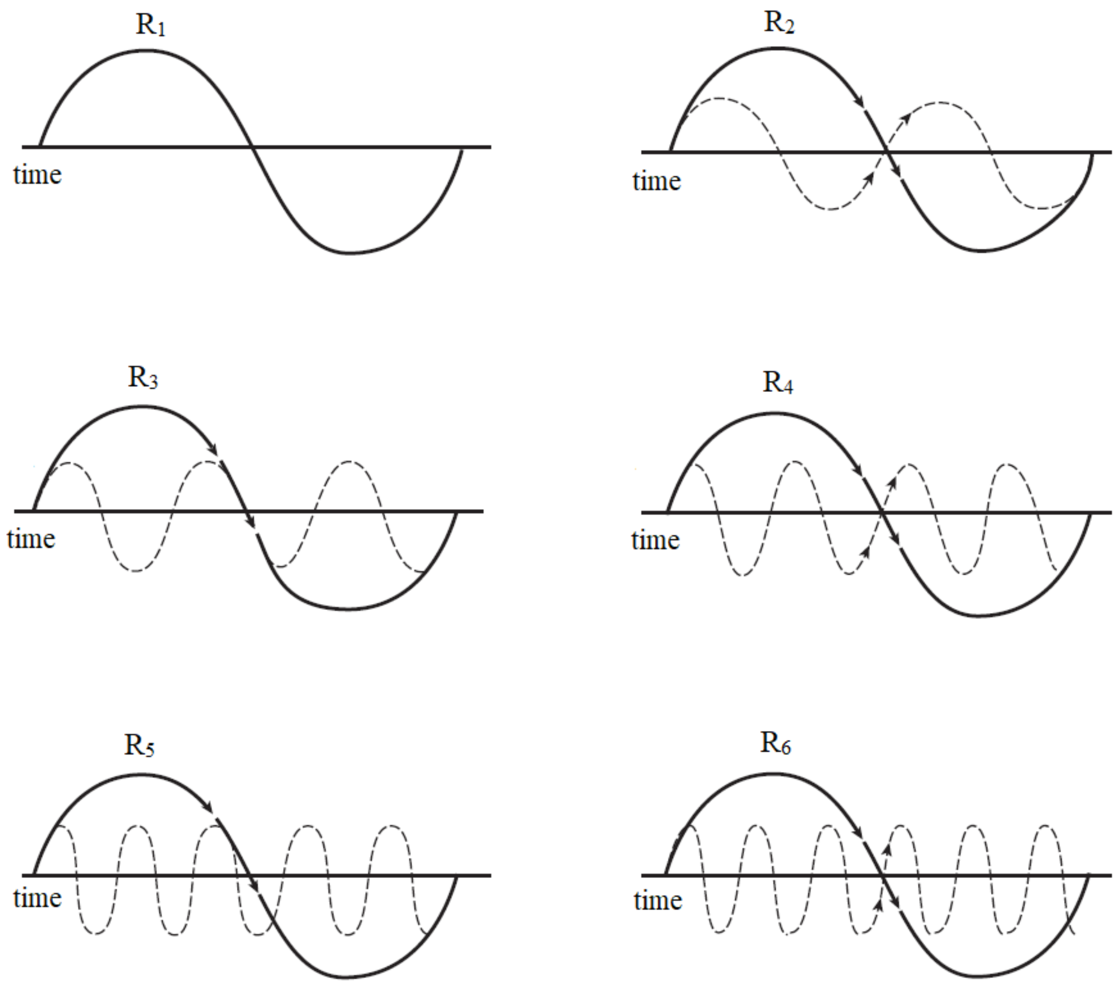


Figure 17. R_1 and its odd-numbered multiples reinforce each other (left). R_1 and its even-numbered multiples are opposing forces (right).

The lowest frequency is equal to the velocity of sound (c) that is divided by the wavelength. As the velocity of sound is around 35000 cm per second, the lowest resonant frequency (R_1) of a 17.5-cm-long tube that is open at one end is 500 Hz ($c/\lambda = 35000/70$). The tube resonates at odd multiples of R_1. The reason for this is the fact that even-numbered multiples, e.g. R_2 (1000 Hz), R_4 (2000 Hz) and R_6 (3000 Hz), are not effective and create opposing forces at the point where they and R_1 meet (Raphael, Borden, & Harris, 2011). On the contrary, R_1 and its odd multiples, e.g. R_3 (1500 Hz) and R_5 (2500 Hz), reinforce each other (see Figure 17).

2.2.6 The Perturbation Theory

Chiba and Kajiyama (1941) depicted the resonances of a tube that is closed at one end and open at the other and associated these resonances to those of the vocal tract (see Figure 18). The velocity of air (V) reaches a maximum at the lips, which are the open end of the tube. However, the velocity (V) reaches a minimum but the pressure (P) reaches a maximum near the glottis, which is the closed end of the tube. This is due to the fact that the air molecules have little room to move around owing to the "closed" end of the tube (Raphael, Borden, & Harris, 2011).

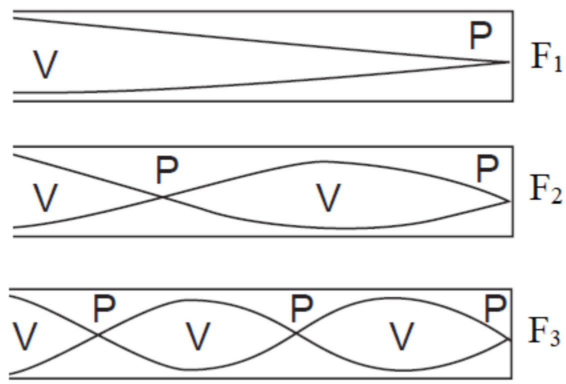


Figure 18. Resonance waves of the first three vowel formants.

According to the perturbation theory, if constriction occurs at V, then the frequency of the resonance in question will decrease and if there is a constriction at P, then this will increase the resonance frequency. The first formant ($R_1=F_1$) has to do with changes in the mouth opening. The first formants of the vowels that require small mouth openings are low. Contrarily, open-mouth vowels have high-frequency first formants. Also, as in low vowels, constriction near the glottis is closer to P than to V, therefore the first formant is high. Constriction near the lips, as in rounded and high vowels, is closer to V than to P, which results in the first formant lowering. The second formant ($R_3=F_2$) is responsive to alterations in the size of the oral cavity. Lip rounding may decrease the frequency of F_2 since constriction occurs near the areas of high velocity. Ladefoged and Johnson (2010) argue that there seem to be two possible ways to raise the second formant. One requires constriction near the glottis, which is in fact quite challenging; however, this needs to be done without any tongue root constriction as it would be near the second V in the resonance wave of F_2. The other option is when constriction occurs with the tongue against the palate, which corresponds to the first P in the resonance wave of F_2. The same rules apply to alter the frequency of F_3 as well.

2.2.7 Spectra of Vowels

Harmonics are produced as a result of the vocal fold source and occur at integer multiples of the fundamental frequency. Formants, on the other hand, are products of the vocal tract filter which amplify particular harmonics while damping out others. This interaction of formants and harmonics bring about the overall spectral shape. It should be noted that time is not expressed in a spectrum. The amplitudes and frequencies represented are averaged during a certain period of time that is being analyzed. Figure 19 demonstrates the spectrum for the vowel [i].

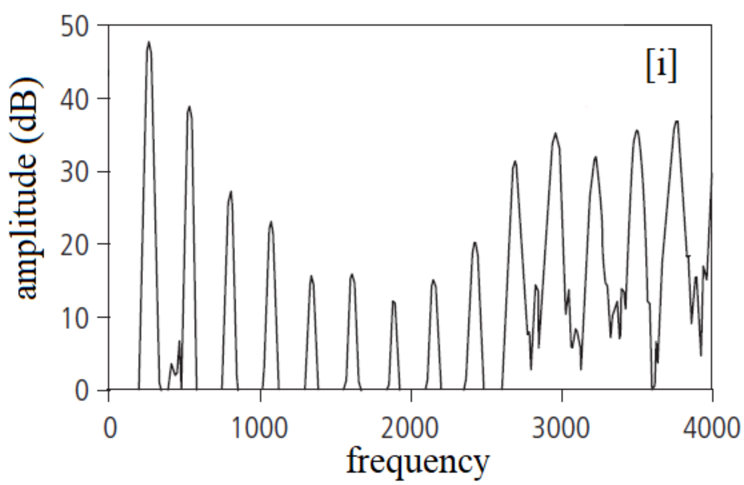


Figure 19. Spectrum for [i].

One can get a hint of what f_o is from a spectrum by looking at where the tenth harmonic lands at (Zsiga, 2013). Harmonics can be seen to be positioned far apart in Figure 19, in which the tenth harmonic is equal to about 2800 Hz, giving an f_o of 280 Hz. Some peaks that are pushed up can be observed. Formant frequencies are visible as these peaks which are emphasized in Figure 20 by drawing a maroon line along the individual harmonics.

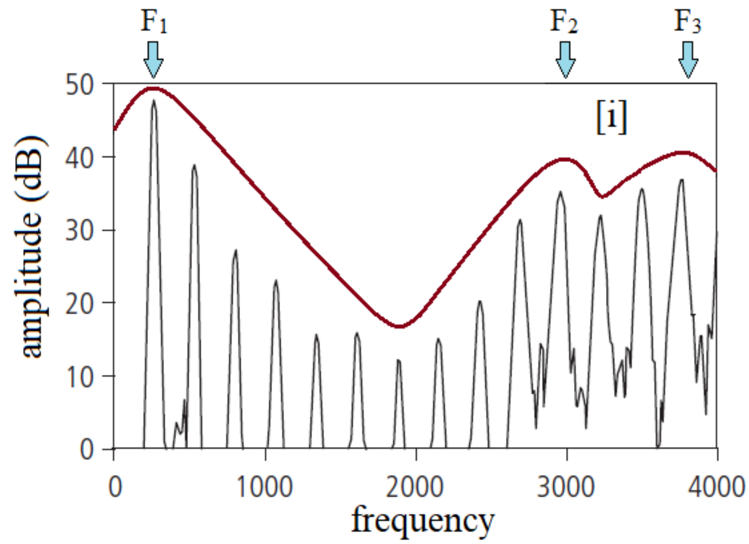


Figure 20. Spectrum for [i] with labeled formants.

The turquoise arrows point those peaks that are labeled as F_1, F_2, F_3. The first two formants are generally considered to be sufficient in order to determine the vowel. Vowel height is traditionally considered to be inversely proportional to F_1. Therefore, high vowels show a low F_1 whereas low vowels are marked by a high F_1 value. For instance, F_1 for the vowel [i] will be lower than F_1 for the low back vowel [ɑ]. In Figure 20, F_1 is around 300 Hz for the vowel [i]. Although these values may vary from one speaker to another due to the differences in the size of the vocal tract, the inverse relationship between vowel height and F_1 holds consistently.

There is also another consistent relationship which concerns the distance between the first two formants: vowel backness is inversely proportional to the spacing between F_1 and F_2. The first two formants seem to be far apart in Figure 20 since [i] is a front vowel. F_1 and F_2 for [i] tend to be further apart than the low back vowel [ɑ]. Again, exact values may change from speaker to speaker; however, the inverse relationship between vowel backness and the spacing between F_1 and F_2 holds consistently. The more front a vowel is, the further apart the spacing between the first two formants is.

Lastly, all the formants, especially F_2 and F_3 tend to be lowered by lip rounding. This has to do with the fact that lip rounding lengthens the whole vocal tract. Therefore, both rounding and backing seem to lower F_2. Zsiga (2013) maintains that these reinforcing acoustic effects justify the fact that back vowels are more likely to be rounded and front vowels to be unrounded cross-linguistically.

2.2.8 Spectrograms of Vowels

In a spectrogram, time is represented on the horizontal scale and frequency on the vertical scale. Areas of high-amplitude energy can be seen as dark stripes which run from left to right. Table 4, which is organized according to the data from Ladefoged and Johnson (2010), displays the averages of the first three formant frequencies of eight American English vowels.

Table 4. Average formant frequencies of eight American English vowels (in Hertz).

	[i]	[ɪ]	[ɛ]	[æ]	[ɑ]	[ɔ]	[ʊ]	[u]
F_1	280	400	550	690	710	590	450	310
F_2	2250	1920	1770	1660	1100	880	1030	870
F_3	2890	2560	2490	2490	2540	2540	2380	2250

In section 2.2.7, we have established the general principle that high vowels are marked by a low F_1. The lowest F_1 values 280 Hz and 310 Hz seem to belong to the high vowels [i] and [u] respectively. Also, an F_1 value of 710 Hz shows that [ɑ] is articulated with a lower tongue position than the others.

The spacing between F_1 and F_2 gives a clue as to vowel backness (see section 2.2.7). There is a difference of 1970 Hz between the F_1 and F_2 values of [i] (2250-280) while this difference is 390 Hz for [ɑ] (1100-710). Since [ɑ] is a back vowel, its F_1 and F_2 values are closer to each other than [i], which is a front vowel.

Figure 21 demonstrates a set of spectrograms for these eight American English vowels occurring in [hVd] contexts. The location of the formants is marked by black arrows. The formant values in Figure 21 are the means of several American English speakers, therefore they may differ slightly from those of Table 4 as those words were pronounced by a single American English speaker. In addition, Table 4 represents isolated vowels whereas Figure

21 shows some coarticulation effects, that is, the effects of the word-final consonants in this context.

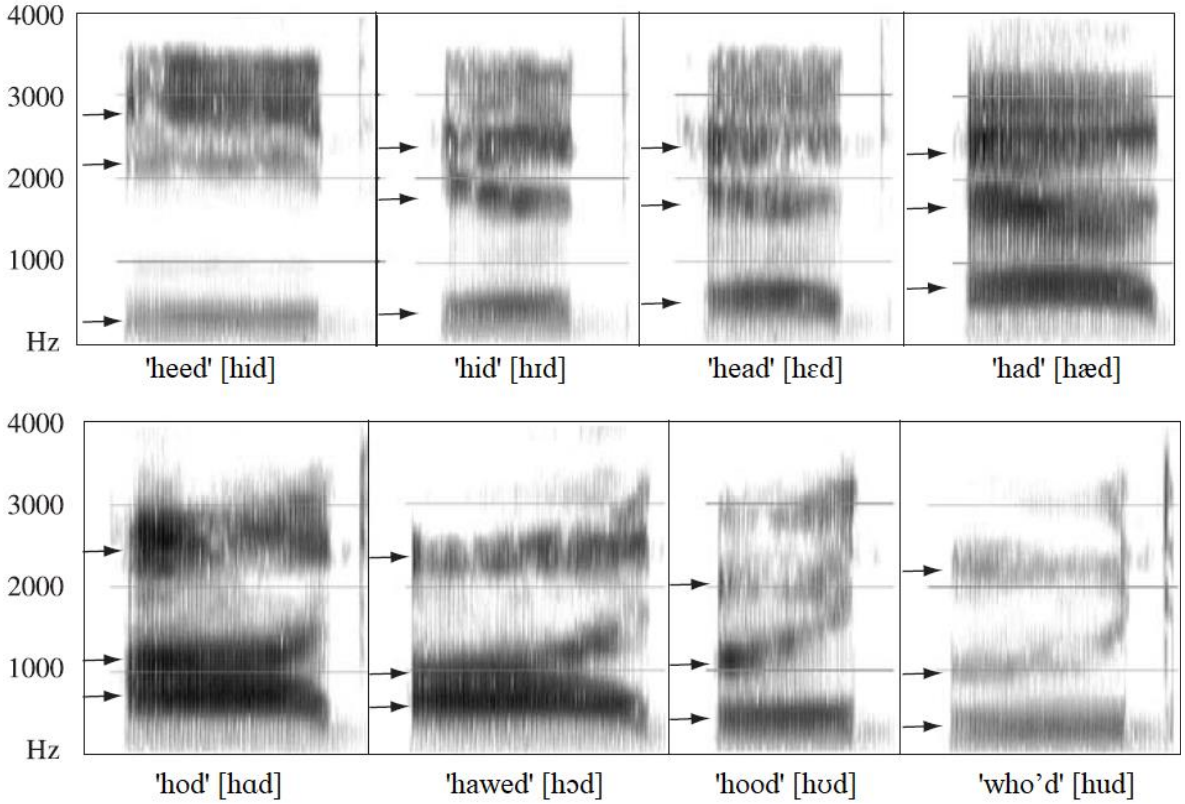


Figure 21. Spectrograms for eight American English vowels in [hVd] contexts (adapted from Ladefoged and Johnson **(2010)**).

In the spectrograms, one can see relatively low F_1 values for high and near-high vowels, i.e. [i], [ɪ], [ʊ] and [u]. Also, the vowels produced with a lower tongue, [ɑ], [æ], [ɔ] and [ɛ], are represented with higher F_1 frequencies. Another point is that F_1 and F_2 seem to be further apart for the front vowels, i.e. [i], [ɪ], [æ] and [ɛ], than the back vowels, i.e. [ʊ], [u], [ɑ] and [ɔ].

2.3 PHONOLOGY

The physical characteristics of speech production is crucial to linguistic study. The next step to take is to study the more abstract relationships between sounds. The term for this study is phonology. Patterns of language sounds in terms of discrete mental symbols concern phonology (Odden, 2013). One such pattern is the relationship of two sounds which help distinguish distinct words in one language but may be just “two ways of saying the same sound” in a different language.

2.3.1 Complementary Distribution

Sounds that are phonetically similar may be grouped under a basic sound. This basic sound group is referred to as a **phoneme** and **allophones** are the other sounds under this group. Phonemes are in contrast with each other whereas allophones are not. If two sounds never occur in the same environment, then this mutually exclusive relationship is called **complementary distribution**. The surrounding sounds and some boundaries, e.g. the syllable or word boundary, constitute the **environment**. English provides an example for complementary distribution. Below are examples of words with [pʰ] and [p].

Table 5. Examples for aspiration in English.

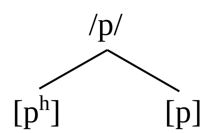
[pʰ]		[p]	
pool	[ˈpʰuːl]	spool	[ˈspuːl]
pin	[ˈpʰɪn]	spin	[ˈspɪn]
topaz	[ˈtʰoʊˌpʰæz]	happy	[ˈhæpi]
play	[ˈpʰleɪ]	aspire	[əˈspaɪəɹ]
appear	[əˈpʰɪɹ]	aspirate	[ˈæspəɹeɪt]

In such a data set, it is assumed that these forms represent the language as a whole since giving all the words containing [pʰ] and [p] would be tiresome. We can create Table 6 according to the environments of [pʰ] and [p] provided in Table 5.

Table 6. Distribution of [pʰ] and [p] in English.

	#___	s___	V___V́	V___V̥
[pʰ]	*p*in		a*pp*ear	
[p]		s*p*in		ha*pp*y

In Table 6, # marks the word boundary, V̊ indicates an unstressed vowel and V́ is a stressed vowel. The underscores show the positions of the sounds in question. [p^h] occurs word-initially regardless of the following sound and appears at the beginning of a syllable that receives primary or secondary stress. [p] appears after [s] regardless of stress and at the beginning of an unstressed syllable. Only one of the sounds seems to appear at each environment. Therefore, they are said to be in complementary distribution and can be grouped together as a phoneme: [p^h] and [p] are allophones of the phoneme /p/. Conventionally, allophones of a phoneme are represented as such:



2.3.2 Coincident Distribution

Aspirated and unaspirated /p/ do not contrast in English; however, in Hindi, they can occur in the same environments as in *t^{h}al* and *tal* (Ladefoged & Johnson, 2010). This can be referred to as **coincident distribution** (Bloch, 1953). These two words differ only in one sound and have different meanings, thus forming a **minimal pair**. This example shows that /p^h/and /p/ are contrastive and distinct phonemes in Hindi. Table 7 demonstrates the role of aspiration in other voiceless stops as well.

Table 7. Coincident distribution in Hindi.

Voiceless aspirated		Voiceless unaspirated	
[p^{h}al]	‘knife blade’	[pal]	‘take care of’
[t̪^{h}al]	‘plate’	[t̪al]	‘beat’
[ʈ^{h}al]	‘wood shop’	[ʈal]	‘postpone’
[tʃ^{h}ʌl]	‘deceit’	[tʃʌl]	‘walk’
[k^{h}an]	‘mine’	[kan]	‘ear’

In fact, in addition to voiceless aspirated and unaspirated stops, voiced and breathy voiced stops can be added to Table 7 since these sounds contrast as well (e.g. [p^{h}al], [pal], [bal] and [b^{ɦ}al], respectively). However, the main point here is to show the difference roles aspiration takes in different languages, therefore it seems sufficient to only include words that have voiceless aspirated and unaspirated stops.

2.3.3 Overlapping Distribution

In Table 8, some Spanish words are given (Navarro, 1918; Harris, 1983). The distribution of the rhotics in Table 8, namely voiced tap and voiced trill sounds, seems to be more complicated than the previous examples.

Table 8. Overlapping distribution in Spanish.

transcription	word	gloss
[roxo]	rojo	‘red’
[raθon̪]	razón	‘reason’
[onra]	honra	‘honor’
[alreðeðoɾ]	alrededor	‘about’
[foro]	forro	‘lining’
[foɾo]	foro	‘forum’
[pɛɾo]	pero	‘but’
[pɛro]	perro	‘dog’
[pɾað̞o]	prado	‘meadow’
[kɾɛθɛɾ]	crecer	‘to grow’
[d̪aɾ]	dar	‘to give’
[pɛɾla]	perla	‘pearl’

The trill [r] occurs at the beginning of a syllable after a consonant and at the beginning of a word. The tap [ɾ], on the other hand, appears after a consonant in the same syllable, at the end of a syllable before a consonant and at the end of a word. However, both sounds appear between vowels. This complicated distribution can be made clear by setting out Table 9 where $ marks a syllable boundary.

Table 9. Distribution of [r] and [ɾ] in Spanish.

	#___	___#	V___V	C$___V	___$C, $C___
trill [r]	[raθon̪]		[pɛro]	[onra]	
tap [ɾ]		[kɾɛθɛɾ]	[pɛɾo]		[pɛɾla], [kɾɛθɛɾ]

In Table 9, we can see that both sounds can occur in the environment V___V. Therefore, they contrast in this environment. However, this does not seem to be the case in all the other environments. This is called **overlapping distribution**. Although we can see certain environments in which only one of those sounds occurs, the fact that both of them appear in the environment V___V indicates that they should be examined as two distinct phonemes (Jensen, 2004). Nevertheless, this does not prevent us from forming a rule concerning the environments in which they do not contrast.

2.3.4 Free Variation

Separate phonemes can occur in the same environment in which they serve to contrast utterances. It is a possibility that some phonetically similar sounds can occur in the same environment, but do not contrast utterances. The distinction between phonemes and allophones is evident; however, this phenomenon, called **free variation**, may obscure the identification of phonemes. Table 10 shows a set of words from English containing the voiceless bilabial stop.

Table 10. Free variation in English.

[p]		[pʰ]		[p̚]	
spin	[ˈspɪn]	pin	[ˈpʰɪn]	elapse	[ɪˈlæp̚s]
aspire	[əˈspaɪəɹ]	passive	[ˈpʰæsɪv]	adopt	[əˈdɑːp̚t]
aspirate	[ˈæspəɹeɪt]	disappointed	[ˌdɪsəˈpʰɔɪntɪd]	overslept	[ˌoʊvərˈslep̚t]
copy	[ˈkʰɑːpi]	topaz	[ˈtʰoʊˌpʰæz]	ape	[ˈeɪp̚]
opera	[ˈɑːpərə]	play	[ˈpʰleɪ]	captain	[ˈkʰæp̚tɪn]
sip	[ˈsɪp]	sip	[ˈsɪpʰ]	sip	[ˈsɪp̚]

In addition to [p^h] and [p] in Table 5, a third sound, the unreleased stop [p̚] has been added to Table 10. The unreleased stop [p̚] occurs word-finally and before another consonant. Table 11 is constructed according to the distribution of these three allophones.

Table 11. Distribution of [p], [p^h] and [p̚] in English.

	#___	___#	s___	___C	V___V́	V___V̊
[p]		si*p*	*sp*in			o*p*era
[p^h]	*p*assive	si*p*			disa*pp*ointed	
[p̚]		si*p*		oversle*p*t		

In Table 11, the environment ___# resembles the Spanish case where both the tap [ɾ] and the trill [r] appear in the intervocalic environment. However, in Spanish, the two words, *pero* and *perro*, form a minimal pair. [pεɾo] means 'but' and [pεro] means 'dog'. Contrarily, the meaning of *sip* does not change in the environment ___#, whether the stop is pronounced [p], [p^h] or [p̚]. As the entries in the environment ___# are not different words, this is an example of free variation. The distribution of the three allophones in the other environments shows that they are in complementary distribution in most of the environments; however, they are in free variation word-finally.

2.3.5 Phonological Notation

In light of the preceding sections, two levels of representation can be established, namely phonemic level, which has information about contrasts in the phonology of a language and phonetic level, which identifies allophones of the underlying phonemes. The underlying phonological representation is conventionally marked by slashes (e.g. /i/) while square brackets are used for phonetic symbols (e.g. [i]). The linking between these two levels is usually done via statements that specify the distribution of allophones. Such statements are called phonological rules which are given schematically as follows:

$$A \rightarrow B \ / \ X\_\_\_Y$$

This formula states that A becomes (→) B in the environment (/) of being followed by Y and preceded by X. The underscore (___) indicates the position of the sound that is affected by the rule, which is A in this case. As an example, vowel phonemes in English are typically *nasalized* before a nasal consonant. Therefore, /fæm/ is realized as [fæ̃m]. This nasalization process can be formalized as follows:

/æ/ → [æ̃] / ___ /m/

This means that /æ/ becomes [æ̃] when followed by /m/. However, this rule might suggest that only /æ/ is nasalized on condition that it precedes /m/. In fact, as mentioned above, all vowels in English are nasalized before any nasal consonant, not just /æ/ preceding /m/, e.g. ‘run,’ ‘sing,’ ‘on,’ ‘seem,’ ‘fame,’ ‘limb,’ etc. If we wrote separate rules for each of the three nasal and twenty or so vowel phonemes, we would end up with some sixty rules to capture all the possibilities. It is more plausible to make generalizations about the sounds to formulate a rule. Therefore, we will have one rule to rule them all. In order to do this, **distinctive features** will be used.

2.3.6 Distinctive Features

Section 2.1.1.3 has introduced phonetic features such as [alveolar], [palatal], [velar], [uvular], etc. in order to specify speech sounds. However, when doing phonological analysis, we often need to refer to some sound groups which consist of more than one place of articulation. Such a group, for example, may be [p, b, f, v]. This group consists of bilabials and labiodentals and cannot be referred to by any combinations of phonetic features which separate only these sounds. Contrarily, if we labeled this group as ‘labial’ instead of ‘bilabial’ and ‘labiodental,’ then we would not be able to handle [f, v] independently from [p, b] (Davenport & Hannahs, 2005).

Due to the **binary** nature of these features, a feature has just two values, ‘+’ or ‘–’. A further problem with phonetic features is that they make possible numerous combinations which are simply impossible to articulate. As a feature is either ‘+’ or ‘-’, some nonsensical groups can be created such as [+labial, +labiodental, +dental, +alveolar, +palatal, +velar, +uvular]. This group cannot be articulated since the tongue would have to be in all these places simultaneously. Therefore, a different, more abstract and less phonetic set of **phonological features** is needed.

2.3.6.1 Major Class Features

The first distinction to be made is between ‘consonants and vowels,’ ‘sonorants and obstruents’. [+/-syllabic] feature generally distinguishes vowels from consonants. [+syllabic] sounds can be the nucleus of a syllable whereas [-syllabic] sounds cannot. It should be noted that the liquids and nasals may be [+syllabic] under certain conditions as in *bottle* [bɑːɾl̩] and *bottom* [bɑːɾm̩], where the diacritics below the lateral and nasal sounds represent syllabicity (see Figure 5 in Section 2.1.2.6). In English, the liquids and nasals may be syllabic; however, it is claimed that any consonant (e.g. obstruents) can be syllabic in Imdlawn Tashlhiyt Berber (Dell & Elmedlaoui, 1985, 1988, 1992; Prince & Smolensky, 2004). [+consonantal] segments, such as plosives, fricatives, affricates, nasals and liquids, are those which have a constriction in the vocal tract which is at least as narrow as what is required for fricatives. [-consonantal] sounds, that is, vowels and glides, lack such a constriction. [+sonorant] sounds, such as vowels, glides, nasals and liquids, are articulated with a constriction which allows the air in front of it and behind it to be fairly equal while this is not observed in [-sonorant] sounds (Gussenhoven & Jacobs, 2011). [+sonorant] segments have greater acoustic energy than [-sonorant] sounds (Hayes, 2009). According to Davenport and Hannahs (2005), [+sonorant] sounds show a clear formant pattern whereas [-sonorant] segments lack such a pattern.

Table 12 shows the possibility of eight categories to be identified with the combination of these three features. Although certain categories are rather uncommon, the entire list of possibilities is provided in Table 12.

Table 12. Major class features.

+syll +cons +son	→	syllabic sonorant consonants (syllabic nasals, laterals, trills and taps)
+syll +cons -son	→	syllabic obstruents in Berber
+syll -cons +son	→	vowels
+syll -cons -son	→	syllabic [h] and [ʔ][1]
-syll +cons +son	→	sonorant consonants (nasals, laterals, trills and taps)
-syll +cons -son	→	obstruents
-syll -cons +son	→	glides and non-lateral approximants
-syll -cons -son	→	[h] and [ʔ]

[1] This category is filled simply for purpose of completeness. Seemingly, syllabic [h] and [ʔ] do not exist in any language (Jensen, 2004).

2.3.6.2 Place Features

[+/-anterior] distinguishes sounds that are articulated at or in front of the alveolar ridge from others. Therefore, bilabials, labiodentals, dentals and alveolars are [+anterior] since they are produced with a major constriction at or in front of the alveolar ridge while sounds such as retroflex, palatal, velar, pharyngeal sounds are [-anterior]. The feature [+coronal] represents sounds whose articulation involves raising the tongue tip or blade whereas sounds which are [-coronal] do not have such a gesture. We can have four possibilities based upon these two binary features as illustrated in Table 13.

Table 13. Place features.

	bilabial labiodental	dental alveolar	postalveolar retroflex	palatal and further back
ant	+	+	-	-
cor	-	+	+	-

For instance, these four possibilities are sufficient for English plosives and affricates to be distinguished as shown in Table 14.

Table 14. Place features for English stops and affricates.

	[p]	[t]	[tʃ]	[k]
ant	+	+	-	-
cor	-	+	+	-

Chomsky and Halle (1968) presents another place feature called [distributed], which is only used for [+coronal] sounds. [+distributed] sounds, basically, involve a relatively long constriction whereas [-distributed] segments have a short contact. In practice, this distinction differentiates [+distributed] laminal coronals from [-distributed] apical coronals. This feature is responsible for the contrast between alveolars and dentals and for the contrast between prepalatals and postalveolars (Jensen, 2004). Therefore, it is deemed redundant in English phonology. However, Australian languages commonly have such contrasts, using the four possibilities provided by these features (Gussenhoven & Jacobs, 2011). For example, four coronal nasals and stops seem to contrast in Kayardild as shown in Table 15 (Evans, 1995).

Table 15. A four-way opposition of coronal nasals and stops in Kayardild.

	dental	alveolar	prepalatal	retroflex
	[t̪], [n̪]	[t], [n]	[c], [ɲ]	[ʈ], [ɳ]
ant	+	+	-	-
distr	+	-	+	-

2.3.6.3 Manner Features

[-continuant] sounds are defined by a complete closure in the oral tract. Therefore, plosives such as [p], [t], [k], affricates such as [tʃ], [ts], nasals such as [m], [n], [ŋ] and the glottal stop [ʔ] are regarded as [-continuant]. [+continuant] sounds are produced such that airflow is allowed to pass through the mouth. This does not mean that a [+continuant] sound must be a fricative. Fricatives generally refer to the class that is defined by the combination of features [+cont, -son]. Liquids, glides and vowels are also considered as [+continuant] in addition to fricatives.

In [+nasal] sounds, the velum is lowered and the airflow passes through the nasal cavity. However, [-nasal] sounds do not have such a process. In addition to consonants, the feature [+/-nasal] is relevant for vowels as well. Nasalized vowels (e.g. [ɛ̃], [ɔ̃], etc.) can be seen in languages such as Yoruba (Bamgboṣe, 1969) and French.

[+/-strident] is only appropriate when obstruents are in question. Acoustically, [+strident] sounds such as [s] and [ʃ] are indicated by greater noisiness than [-strident] sounds such as [θ] and [ð] (Chomsky & Halle, 1968). We can capture sibilants (i.e. [s z ʃ ʒ tʃ dʒ]) by combining the features [+cor] and [+strid].

[+lateral] segments are marked by the blockage of central airflow, allowing the air to escape from one or both sides of the tongue (e.g. [l], [ʎ], [ʟ], etc.). Other sounds are [-lateral].

The feature [+delayed release] is used to distinguish between affricates and stops. Although stops and affricates are both [-continuant], the latter group of sounds differs in that its members are [+delayed release].

2.3.6.4 Laryngeal Features

If the vocal folds are far apart during the articulation of a sound, then that sound is considered as [+spread glottis]. Therefore, aspirated obstruents (e.g. [pʰ] and [tʰ]), breathy sonorants (e.g. [m̤] and [a̤]), [h] and [ɦ] are defined by the feature [+s.g.].

When producing [+constricted glottis] sounds, the vocal folds are firmly constricted. [+c.g.] sounds include implosives (e.g. [ɓ] and [ʄ]), ejectives (e.g. [p’] and [t’]), laryngealized sonorants (e.g. [m̰] and [a̰]) and the glottal stop [ʔ].

Segments are [+voice] if the vocal folds vibrate during the articulation. [+voi] sounds are sonorant consonants (e.g. [ɲ] and [l]), voiced obstruents (e.g. [d] and [ɣ]) and vowels (e.g. [ʌ] and [ø]).

2.3.6.5 Vocalic Features

Cross-linguistically, vowels are claimed to hold several uniform distinctive feature values: [+syll, -cons, +son, -ant, -cor, -distr, +cont, -strid, -lat, -del.rel] (Hayes, 2009). Vowels typically hold the features [+voi, -s.g., -c.g.] as well; however, in languages such as !Xoo and Mazateco, [+s.g.] and [+c.g.] are used contrastively since glottalization and breathy voicing are present in those languages (Odden, 2013). We can also encounter [-voi] vowels phonetically in Chatino (Jensen, 2004), in Japanese (Labrune, 2012), in Acoma (Miller, 1966), in the Indo-Iranian languages in the Indic/Iranian border area, in some Bantu languages and even in English (Ladefoged & Maddieson, 1996). According to Odden (2013), the phonological status of voiceless vowels is unclear, therefore it is a possibility that there are no [-voi] vowels phonologically.

In [+high] vowels, the body of the tongue raises above the neutral position while [-high] vowels do not exhibit such a process. In the articulation of [+low] vowels, the tongue is lowered with regard to the neutral position. [+back] vowels are those in which the tongue is retracted from the neutral position whereas [+front] vowels are those in which the body of the tongue is fronted. In the production of [+round] vowels, the lips are protruded. The feature [+tense] can be used to describe vowels produced with considerable muscular effort. According to Davenport and Hannahs (2005), as a result of this muscular effort, [+tense] vowels tend be more peripheral and longer (e.g. [iː], [oː], etc.).

Another characterization of vowels is the feature [+/-Advanced Tongue Root]. This feature is generally useful in West African languages where vowels may differ with respect to the tongue root position (Ladefoged, 1964). [+ATR] vowels are articulated by pushing the root of the tongue forward from the neutral position. The phonetic difference between [+/-ATR] and [+/-tense] has led to some debate (Odden, 2013). [+/-ATR] is occasionally used instead of [+/-tense] when describing languages (e.g. English) (Davenport & Hannahs, 2005). Lindau (1979) has pointed out that [+/-tense] and [+/-ATR] features are different from each other in the acoustic sense. However, the tongue root of the lax vowels has been found to be not so much different from that of the tense vowels (Harshman, Ladefoged, & Goldstein, 1977; Ladefoged & Harshman, 1979). In addition, Jackson (1988) has observed that English does not specify vowels in relation to [+/-ATR] while Akan does. According to Ladefoged and Maddieson (1996), [+/-ATR] only seems to be a concomitant of vowel height. As a concomitant of the raising of the tongue, [+/-ATR] can be viewed as similar to [+/-tense] (Davenport & Hannahs, 2005). The entire list of vowels in the IPA with their vocalic features is shown in Table 16 in which [+/-ATR] is not included due to the so-called similarity between [+/-ATR] and [+/-tense].

It should be noted that [ɜ] and [ɐ] are missing in Table 16. [ɐ] stands for a low central unrounded vowel in the IPA chart and the reason why it is not included in the table is that this position in filled with [a] by Hayes (2009). Therefore, [a] is [-front] in Table 16 contrary to the fact that it is represented as [+front] in the IPA chart (see Figure 3 in Section 2.1.2.4). For the [+front, -high, +low] position, [æ] is used. [ɜ] is also deemed extravagant in Table 16 since the IPA provides three mid central unrounded vowels [ɘ], [ə] and [ɜ]. [ɘ] designate the [+tense] mid central vowel while [ə] is used for the [-tense] one.

Table 16. Features of the IPA vowels (adapted from Hayes **(2009)**).

	i	y	ɨ	ʉ	ɯ	u	ɪ	ʏ	ʊ	e	ø	ɘ	ɵ	ɤ	o
[hi]	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-
[lo]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
[bk]	-	-	-	-	+	+	-	-	+	-	-	-	-	+	+
[fr]	+	+	-	-	-	-	+	+	-	+	+	-	-	-	-
[rd]	-	+	-	+	-	+	-	+	+	-	+	-	+	-	+
[tns]	+	+	+	+	+	+	-	-	-	+	+	+	+	+	+

	ɛ	œ	ə	ɞ	ʌ	ɔ	æ	ɶ	a	ɑ	ɒ
[hi]	-	-	-	-	-	-	-	-	-	-	-
[lo]	-	-	-	-	-	-	+	+	+	+	+
[bk]	-	-	-	-	+	+	-	-	-	+	+
[fr]	+	+	-	-	-	-	+	+	-	-	-
[rd]	-	+	-	+	-	+	-	+	-	-	+
[tns]	-	-	-	-	-	-	-	-	-	-	-

2.7 AN ALTERNATIVE VOWEL CHART

2.7.1 Problems with the IPA Vowels

A particular problem that the IPA vowel system has is that it provides a total of eight central vowels [i.e. [ɨ], [ʉ], [ɘ], [ɵ], [ə], [ɜ], [ɞ] and [ɐ]) although there is little to no evidence that they should be distinguished from back vowels which have the same height or rounding (Jensen, 2004). Along the same line, Wells (2009) claims that several IPA vowel symbols were motivated simply by an overzealous attempt to label some missing sections on the chart.

An awkward issue with the IPA is that no symbol is designated for the low central unrounded vowel position despite this sound being "the most common of all vowels in the world's languages" (Hayes, 2009). Hayes follows the practice of designating [a] as a central vowel rather than a front vowel as it is in the IPA. Jensen (2004) also employs [æ] instead of [a] for the low front unrounded vowel and further discusses the use of [a], thus avoiding the symbol [a] altogether.

The IPA chart also appears to disregard the lip postures of vowels in that any place selected on the chart can represent more than just one vowel. Primary cardinal vowels occur at the same position as secondary cardinal vowels even though the latter are articulated with a reversed lip posture.

2.7.2 The Sound Space of Vowels

Vowel sounds are areas which occur within a continuous space. Therefore, each vowel of a language phonetically corresponds to an area of values and there seems to be a continuum between two selected vowels. Similarly, such a continuous space also exists between green, blue and red as shown in Figure 22 which demonstrates perceptible colors for human beings.

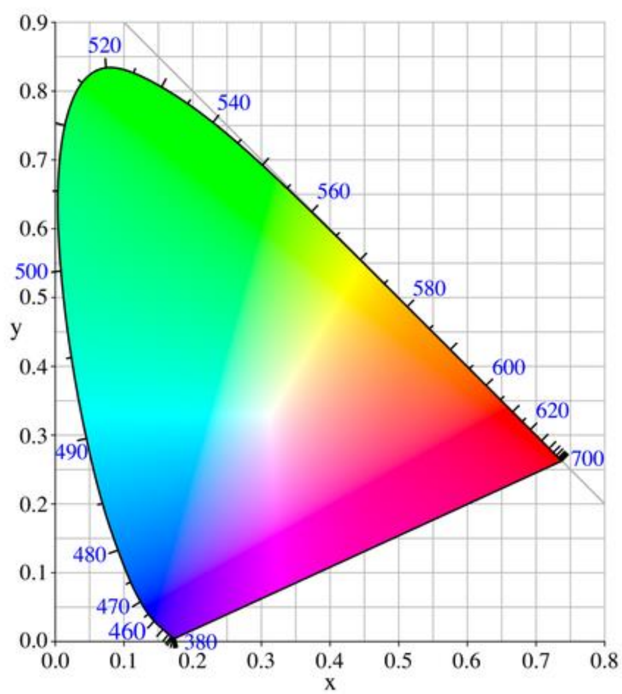


Figure 22. Color space chromaticity diagram of the Commission International de L'Eclairage (CIE).

The sound space of vowels can also be graphed such that the vowels [i], [a] and [u] are at the corners. The 'white' center of the diagram in Figure 22 corresponds to schwa (i.e. [ə]). The analogy made between the vowel and color spaces are visualized in Figure 23.

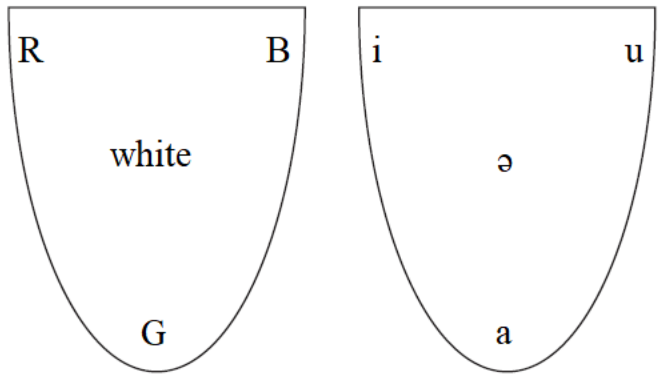


Figure 23. The color space (left) and the vowel space (right).

The color space can be realized very differently in languages and the phonological interpretations of the vowel space vary in a similar vein. Vietnamese uses *xanh* to cover the area in the color space which is divided into *blue* and *green* in English (Jameson & Alvarado, 2003). Setswana is another language which uses *tala*, sometimes translated as the portmanteau word "*grue*[2]", to deal with that color space (Davies et al., 1992). On the other hand, English possesses just one basic color term, *blue*, for the color space that Russian obligatorily divides into *goluboj* and *sinij* which refer to what English calls *light blue* and *dark blue* respectively (Winawer et al., 2007). Similarly, Paramei, D'Orsi and Menegaz (2014) argue that Italian can be claimed to have three basic color terms, *blu* "dark blue," *azzurro* "blue" and *celeste* "light blue," for the color space called *blue* in English. An analogy can be made between color space and vowel classifications. The area of the vowel space which is divided into *i* and *e* in Spanish and Japanese is divided into *i*, *y*, *e*, *ø*, *ε* and *æ* in Danish (Ladefoged & Johnson, 2010). In similar fashion, the region of the vowel space which consists of *u*, *o* and *ɔ* in Italian (Rogers & d'Arcangeli, 2004) seems to be divided into *ɯ* and *o* in Japanese (Nishi et al., 2008).

[2] For green and blue.

The triangular vowel space exhibits our sensitivity to varying structures in the acoustic spectrum, that is, [u] is defined by low resonances, [a] by mid-range resonances and [i] by a coalescence of low and high resonances. A diagram of the vowel space can be derived by plotting the first formant to the second formant. In Figure 24, the paramountcy of [i], [a] and [u] is evidently depicted as they are in three different corners and the outer edge of the sound space is where the primary cardinal vowels are located.

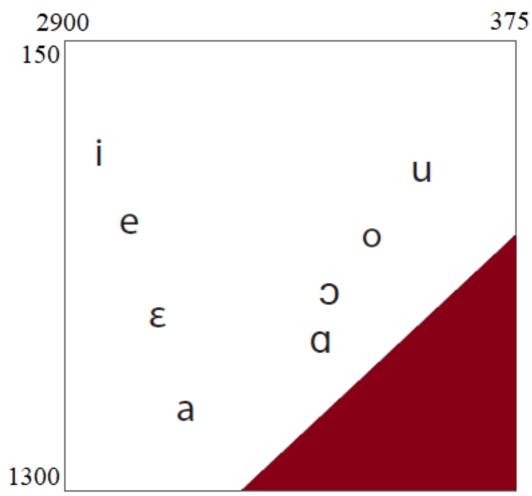


Figure 24. Primary cardinal vowels of Daniel Jones (y-axis F_1, x-axis F_2, logarithmic scales).

Figure 24, in which the first formant is graphed from top to bottom and the second formant from right to left, shows a diagram created from the analysis of the recordings of Daniel Jones in PRAAT (Lindsey, 2017). The colored bottom right-hand corner represents the impossible area where F_1 is higher than F_2. The triangular shape is already noticeable for Figure 24.

2.7.3 A Tongue Chart

Phoneticians largely approve of the proposition of defining vowels by their places in a tongue space. Alexander Melville Bell (1867), a teacher of speech and the father of Alexander Graham Bell, was the one who proposed two dimensions for the description of vowels: tongue height and tongue backness. Phonologists still use Bell's classifications front/back and high/low. Bell's idea of tongue backness and height was developed by later phoneticians who plotted charts of vowels demonstrating allegedly the highest position of the tongue. We traditionally place F_1 vertically and F_2 horizontally on vowel charts since these phoneticians thought that the y-axis represented the height of the tongue and the x-axis tongue backness. Ladefoged (2001) compared these phoneticians to pre-Galilean astronomers by pointing out that the ancient astronomers were confident in their prediction of how the stars and planets revolved around the world although they were wrong. Similarly, the early phoneticians reckoned that they were illustrating the highest position of the tongue although they were wrong as well. In fact, they were representing formant frequencies. Russell (1928) accuses these phoneticians of "using physiological fantasy" to express acoustic facts.

The International Phonetic Association still promotes the visualization of the vowel space as a tongue space. The *Handbook of the International Phonetic Association* (1999) acknowledges that the boundary of the vowel space is obtained by connecting the highest points of the tongue for the vowels [i], [a], [ɑ] and [u]. As a result, the stylization of this vowel space can be the traditional quadrilateral.

The *Handbook of the International Phonetic Association* (1999) concedes that the auditory spacing between the vowels do not depend solely upon articulation and that is why the vowel quadrilateral should be considered as an 'abstraction,' rather than a direct representation of the position of the tongue. Actually, one can observe triangularity to some extent on the vowel quadrilateral in that it seems to narrow down towards the bottom. The lack of central vowels at the bottom of the quadrilateral appears to be purely illogical (Lindsey, 2017).

As mentioned in Section 2.7.1, the tongue quadrilateral seems to ignore the lip positions in that any place that is chosen on it can correspond to more than one vowel. Each primary cardinal vowel happens to occupy the same place as a secondary cardinal vowel which has a reversed lip position. The fact that any place on the IPA vowel chart can represent more than one vowel quality greatly undermines the credibility of it as a vowel chart.

If the lip position of a vowel is altered, then it means that its place in sound space is altered. Since the primary cardinal vowels are peripheral, changing the lips positions of these vowels naturally de-peripheralizes them. Therefore, the secondary cardinal vowels tend to be more central in sound space than the primary cardinal vowels. Figure 25 shows Daniel Jones' vowel space which is extended with the addition of some vowels.

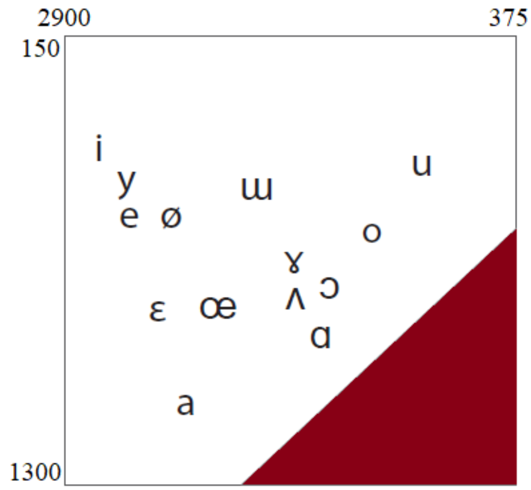


Figure 25. Primary cardinal vowels of Daniel Jones with additional vowels (y-axis F_1, x-axis F_2, logarithmic scales).

2.7.4 A Triangular Vowel Chart

The non-primary vowels in Figure 25 may seem to be in disarray. Lindsey (2017) makes an attempt to organize Figure 25 and arrives at Figure 26 with the help of averaging the formant frequencies of John Wells' and Daniel Jones' vowels and modifying the averages to expand equal spacing.

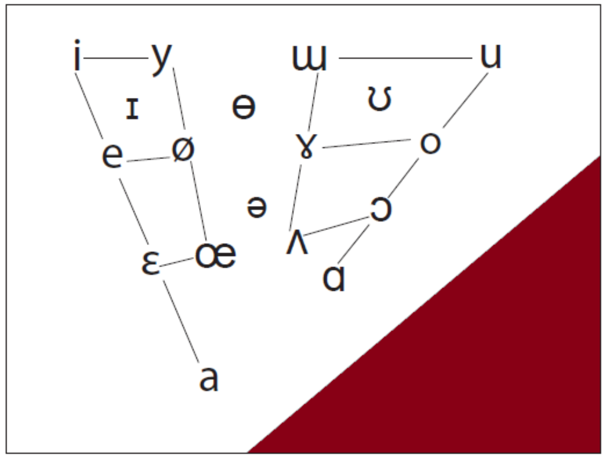


Figure 26. Vowel chart with additional lines (y-axis F_1, x-axis F_2, logarithmic scales).

With the help of some stylization, the graph in Figure 26 can be converted into a vowel chart which is, in the words of Russell, based on ‘acoustic fact’ than ‘physiological fantasy’. Such a chart is visualized in Figure 27, which can be seen to be very conservative compared to the IPA quadrilateral. Jones’ primary cardinal vowels, i.e. [i], [e], [ɛ], [a], [u], [o], [ɔ] and [ɑ], are retained and placed at equidistant points on the periphery. [ɪ], [ʊ], [ə], [ɵ] and [ɐ] are located at very similar positions as they are on the IPA chart. [ɚ] cannot be placed appropriately on the chart in Figure 27 since it can be produced in utterly different manners. Nevertheless, as it is characterized by a low F_3, it would be feasible to place this sound adequately by modifying the chart with a third dimension denoting F_3.

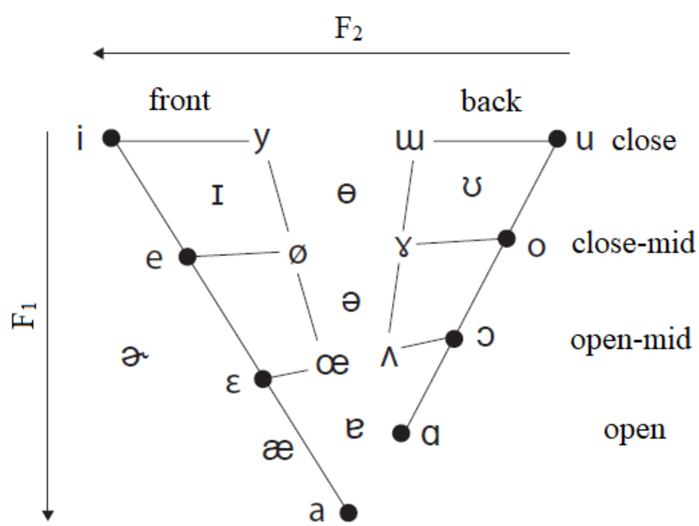


Figure 27. The vowel triangle (Lindsey, 2017).

2.8 STUDIES ON TURKISH VOWELS

Since acoustic phonetics is a field that has grown exponentially, studies on Turkish seem to be discordant with each other. As this study aims to solve this non-uniformity and reveal the diversity of results, thereby coming to an objective conclusion, different sources contradicting each other were analyzed. The sources mentioned below mostly chose not to specify the number of sounds that they dealt with. However, in order to demonstrate the diversity of results, vowel allophones have been counted one by one if not specified in the source. If the number of phones in a study is limited to that of the letters in the alphabet, that study is not included here. Also, if consonants, along with vowels, are examined in a source material, only vowel sounds are referred to as they are the points of interest.

Aksan et al. (1978) state that 18 vowel allophones, 4 of which are <e> sounds, exist in Turkish. The presentation that 10 academics made at Boğaziçi University shows 8 distinct vowel phonemes (Arısoy et al., 2008). Banguoğlu (2007) asserts that Turkish has 9 vowels in his study in which he touches upon many allophones which were borrowed from Arabic and the Ottoman language. Another significant book in the field of Turkish phonetics is *Türkçenin Ses Bilgisi* by Coşkun (2001) who compiled various results from the studies carried out in a phonetics laboratory at Trier University in Germany. As his conclusions are based on a phonetics laboratory, Coşkun's book has a particular place in the field. He claims that 19 total vowels (i.e. 10 short and 9 long vowels) are present in Turkish (Coşkun, 2001). Afterwards, he adds another front vowel ô to his inventory, which equals to 20 vowels in total (Coşkun, 2001). However, at the beginning of his another article, despite starting with 20 vowels, he ends up with 21 with the inclusion of another allophone of <e> (Coşkun, 1999). As there are some inconsistencies with the number of vowels in Coşkun's studies, his latest book is used as a basis, which argues for 21 vowels (Coşkun, 2008). Besides, Demircan (2009) introduces 8 vowels in his book *Türkçenin Ses Dizimi* but he does not include two distinct <e> phonemes that he proposes in the vowel table. If both <e> phonemes are to be counted, then the number of vowel sounds increases to 9. Erem and Sevin's *Milletlerarası*, published in 1947, is one of the oldest and also among the most detailed reference books in the field of Turkish phonetics. It comprises many allophones that are exemplified greatly in various words. The writers pay strict attention to the fact that each allophone in the book should be represented as a symbol in the IPA. The sounds mentioned in the book are counted one by one, making up 14 vowels in total (Erem & Sevin, 1947). İclâl Ergenç, despite studying Turkish phonologically in her book *Türkiye Türkçesinin Görevsel Sesbilimi*, also sheds some light on Turkish phonetics. In this book, she contends that Turkish has 16 vowel sounds (Ergenç, 1989). Afterwards, Ergenç (2002) updates this number as 15 in her dictionary *Konuşma Dili ve Türkçenin Söyleyiş Sözlüğü* which is still the first and only pronunciation dictionary of standard Turkish. Although she does not change the total number of vowels and consonants in her dictionary, she simply omits one <e> sound out of the three due to its frequency of occurrence, which eventually results in 15 vowel sounds. Efrasiyap Gemalmaz (1980), in his article *Türkçenin Fonemler Düzeni ve Bu Fonemlerin İşleyişi*, points out that there are 5 vowel phonemes in Turkish. In his second article *Türkiye Türkçesinde Ses Olayları*, he classifies the sounds with respect to their openness levels and also includes allophones, reporting 19 vowel sounds (Gemalmaz, 1999). In another paper *Sesbilgisi (Phonetics) Ve Sesbilim (Phonology)* by Çiler Hatipoğlu, she maintains that 8 vowels are present in Turkish (Hatipoğlu, 2002). Boğaziçi University Turkish Language Courses Coordination Unit compiled lecture notes of Turkish Language course and published *Türk Dili Ders Notları*, in which 8 vowels are said to be present (Kaya et al., 2005). According to Özsoy (2004), 25 vowel allophones and 8 vowel phonemes are existent in Turkish. In addition, she does not include long vowels to this number. Nevin Selen's *Söyleyiş Sesbilimi, Akustik Sesbilim ve Türkiye Türkçesi*, published in 1979, provides results based on acoustic analyses of sounds which were uttered by a woman and a man with standard Turkish. Those sounds are evaluated in terms of their formants, which makes it a very significant reference book for this study. As a result, 16 vowel sounds are claimed to be present in Turkish (Selen, 1979). Another important book on this issue is *Handbook of the International Phonetic Association* by the IPA, which touches upon the phonetic transcriptions of 29 different languages or dialects. The section devoted to Turkish was prepared by Karl Zimmer and Orhan Orgun. They suggest that 8 vowel sounds exist in Turkish but no classification of those sounds is given (Zimmer &

Orgun, 1999). Considering the effects of the neighboring consonants of vowels, Ergenç and Uzun (2017) maintain that 16 vowels can be claimed to exist in standard Turkish.

The sources above mentioned hardly agree about the number of the vowels in Turkish and this difference should not be overlooked. This diversity is to the extent that it hurts the objectivity of Turkish phonetics. Another worry here is that this may have a negative effect on education about the subject, therefore making room for subjective and disconnected propositions. This study aims to be consistent and provide as objective results as possible by adhering to evidence.

2.9 TURKISH CONSONANTS

Although this study is mainly about creating a vowel inventory of Turkish, one will inevitably see many instances of consonants in various sections. Understanding the nature of the consonants surrounding the vowels is important, especially in the context of phonological rules. Therefore, giving a brief introduction to Turkish consonants does not seem to be a vain attempt. Table 17 shows the phonetic inventory of Turkish consonants, which is used throughout the study. In Table 17, places of articulation are located at the top while manners of articulation are listed in the leftmost column.

Table 17. Phonetic chart of Turkish consonants.

	bilabial		labiodental		dental		alveolar		postalveolar		palatal		velar		glottal	
plosive	p	pʰ			t̪	t̪ʰ					c	cʰ	k	kʰ		
	b				d̪						ɟ		g			
nasal	m		ɱ		n̪								ŋ̟	ŋ		
tap							ɾ									
affricate									tʃ	tʃʰ						
									dʒ							
fricative	ɸ		f		s̪		ɾ̝̊		ʃ		ç				h	
	β		v		z̪				ʒ							
central appr.											j					
lateral appr.					ɫ̪		l									

CHAPTER 3

METHODOLOGY

3.1 PILOT STUDY

The main goal of the pilot study was to explore the possible limitations that the study can have. It was conducted in order to minimalize those limitations and improve the reliability of the results. In light of the pilot study, a number of adjustments were applied and this made it possible to refine the actual study. The methodology of the pilot study is presented with reference to the participants, data collection, procedure and data analysis.

3.1.1 Participants

Two adults aged 26, one male and one female, participated in the pilot study. Both participants were native speakers of Turkish. As it was significant to map the vowels of standard Turkish, it was necessary to choose speakers whose speech is not influenced by any dialect other than the İstanbul dialect. The researchers paid attention to the places of birth of the participants and if the speakers spoke any other dialect, they were not allowed to participate in the pilot study.

The speakers participated in the pilot study on a voluntary basis. They signed a voluntary participation form and were not asked any personal questions such as their political view, sexual orientation, religion, etc. They were explicitly informed verbally and in writing that they had right to leave the study if they wanted to do so and they would not be held responsible in any case.

3.1.2 Data Collection and Procedure

In the first place, 51 different words which contain 12 allophones ([ɑ a e ɛ ɯ i o o̜ ø u u̜ y]) of 8 distinct phonemes (/ɑ e ɯ i o ø u y/) were selected. Every allophone appears 8 times in those 51 words. As the pilot study aimed to represent the actual study, the same 51 words containing a total of 96 (12 x 8) vowel allophones occurring word-initially, word-medially and word-finally were used as in the actual study. Each word was presented to the participants in PowerPoint slides. The data collection was conducted in a nonreverberant room and the recordings were made with a BM-900 Condenser Microphone via Audacity at the sampling rate of 44.1 kHz and 16-bit resolution.

3.1.3 Data Analysis

The PRAAT v. 6.1.14 was used in the analysis of the recordings in the pilot study (Boersma & Weenink, 2020). After the segmentation of the vowels as detailed in Section 3.2.3, the mean F_1, F_2 and F_3 values of the vowels were calculated. Based on these means, graphical representations of the vowel plots were made in RStudio (RStudio Team, 2019) with the help of the package phonR (McCloy, 2016).

3.1.4 Findings

The mean F_1 and F_2 values of the vowels for both speakers (one male and one female) are presented separately in Figure 28.

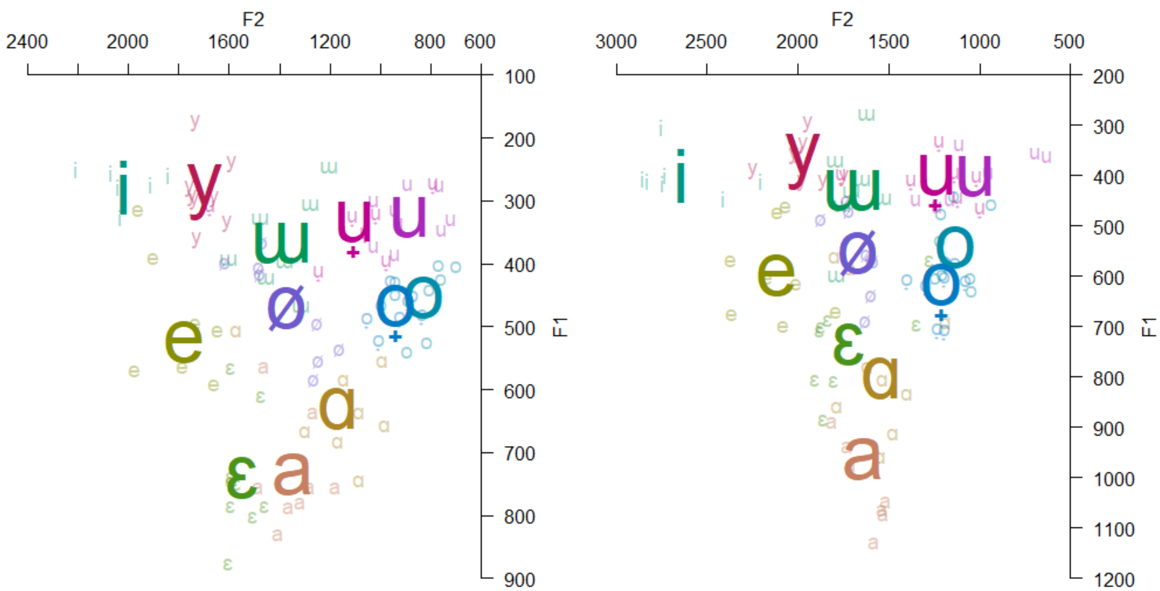


Figure 28. Vowel plots for the male (left) and the female (right) speaker.

In Figure 28, the faded vowels represent the individual vowel tokens while the means are marked by bold IPA symbols. Figure 29 presents only the mean values in bold symbols in order to visualize the vowel plots of each speaker in a clearer way.

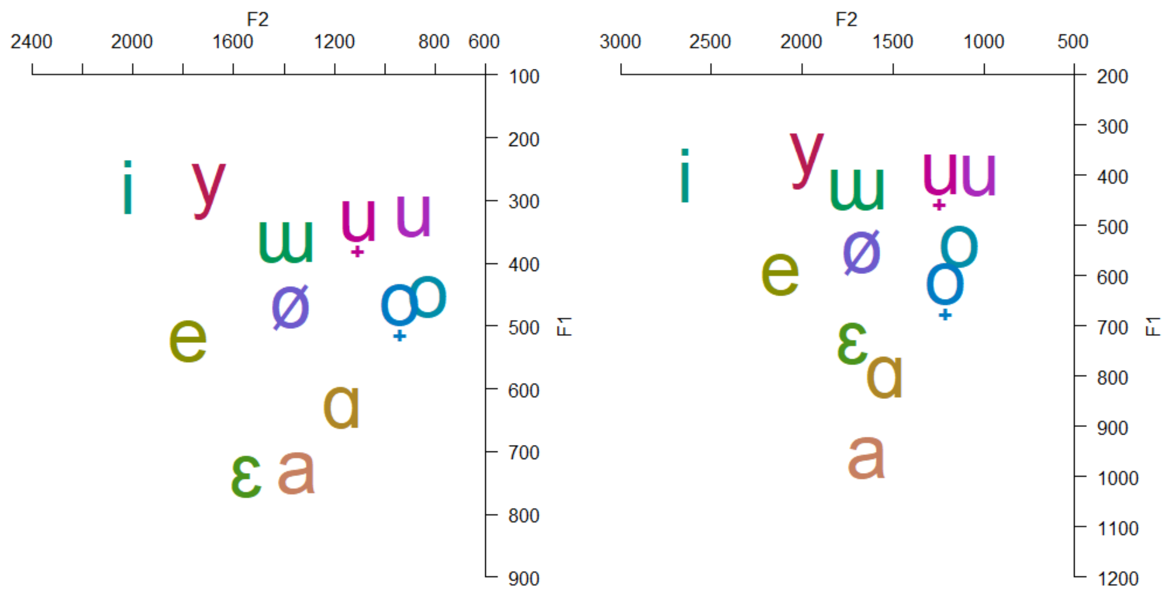


Figure 29. Mean F_1 and F_2 values for the male (left) and the female (right) speaker.

In addition, approximately 68% confidence ellipses, which correspond to ±1 standard deviation of the normal density contour anticipated from the data, are drawn in the location of the mean of each vowel in Figure 30.

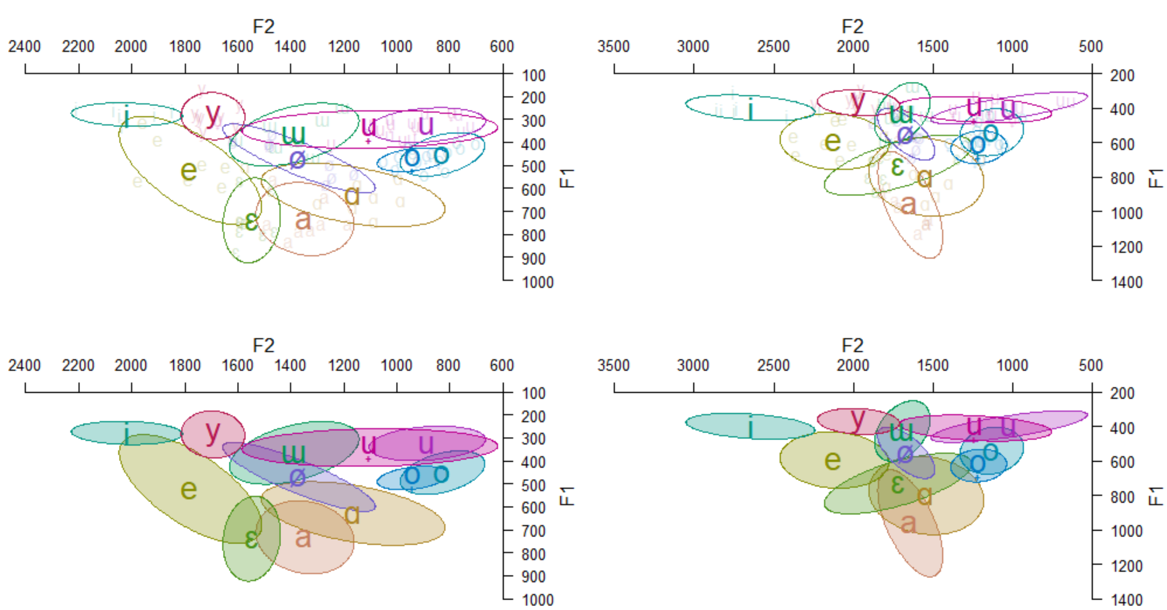


Figure 30. Mean F_1 and F_2 values for the male (left column) and the female (right column) speaker with approximately 68% confidence ellipses.

In Figure 30, the bottom row demonstrates the vowel plots with the ellipses filled in for better visualization. The vowel spaces of both speakers are provided with convex hulls in Figure 31. The plot is color-coded for gender.

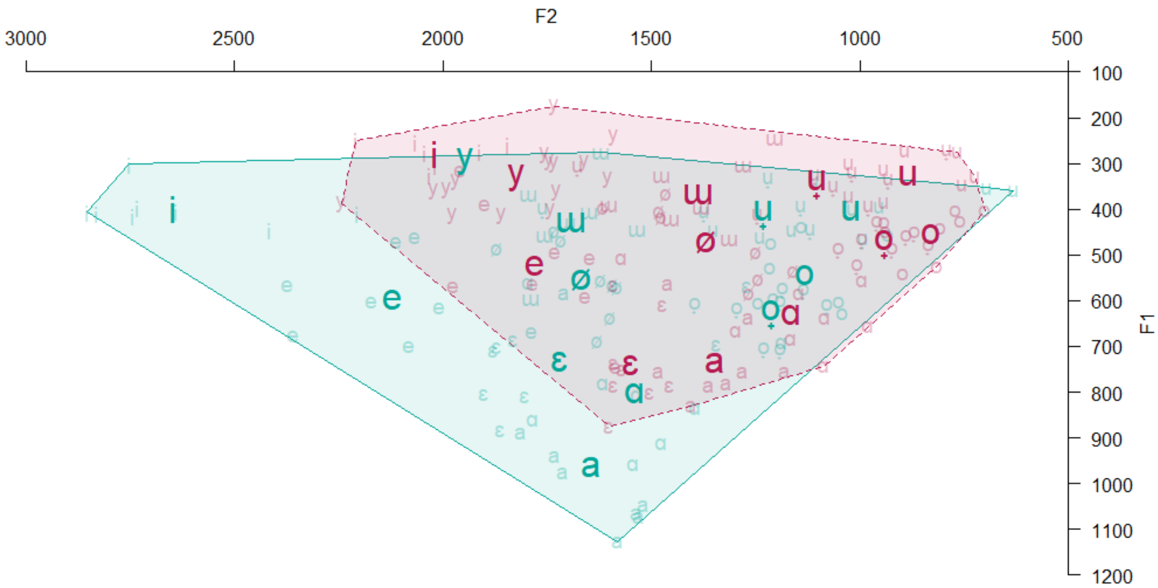


Figure 31. The vowel space of both speakers with convex hulls (green for female and red for male).

3.1.5 Contributions of the Pilot Study to the Experiment

The words shown to the participants included a pair of homographs, namely *sol* ‘musical note g’ and *sol* ‘left’. Also, a word such as *kâr* ‘profit’ with the circumflex ‘^’ can be confused with *kar* ‘snow’ and mispronounced as [kʰɑɾ̥] instead of the correct pronunciation [cʰaɾ̥]. Such situations led to discontinuities in the pilot study during which the participants asked the researchers which pronunciation was intended. Since this condition was believed to disrupt the naturalness of the actual study, such pronunciation errors were attempted to be prevented with the help of providing definitions before each word. The participants were presented with a short definition for each word in PowerPoint slides in the actual study. Only after reading the definition silently, the participants were able to click and see the word itself. As mentioned, the reasoning behind providing short definitions for the words was led by the idea that some words might be mispronounced at first sight without any definition, thus undermining the natural reading that the study aimed to achieve.

In the pilot study, all the vowel plots are provided in Hertz values. However, vowel normalization is a means of comparing acoustic data across individual participants. Vowel normalization is used in the actual study in order to eliminate physical differences and make cross-gender and cross-age comparisons.

3.2 THE STUDY

3.2.1 Participants

Ten adults with a mean age of 28.9, five males and five females, participated in the study. The mean age of the male participants was 29.4 while that of the female speakers was 28.4. All the speakers were native speakers of Turkish. As required by the nature of the study, it was of importance to plot the vowels of standard Turkish. Therefore, it was vital to pick speakers whose speech is not affected by any other dialect aside from the Istanbul dialect. The researchers paid attention to the places of birth of the participants and if the speakers spoke another dialect, they were not allowed to take part in the study.

The participation in the study was on a volunteer basis. The participants were requested to sign a voluntary participation form. It was ensured that they were not to be asked any personal questions including their political view, sexual orientation, religion, etc. The participants were explicitly informed verbally and in writing that they had right to abandon the study at any given time and under no circumstances would they be held responsible.

3.2.2 Data Collection and Procedure

51 words containing 12 allophones ([ɑ a e ɛ ɯ i o o̩ ø u u̩ y]) of 8 phonemes (/ɑ e ɯ i o ø u y/) were chosen. Each allophone occurs 8 times in those 51 words. Those 51 words contain a total of 96 (12 x 8) vowel allophones occurring word-initially, word-medially and word-finally. Each word was presented to the participants with short definitions in PowerPoint slides. The audio recordings were collected in a nonreverberant room with a BM-900 Condenser Microphone via Audacity at the sampling rate of 44.1 kHz and 16-bit resolution.

3.2.3 Data Analysis

The audio recordings in the study were analyzed in PRAAT v. 6.1.14 (Boersma & Weenink, 2020). A broadband spectrogram was used as the window length was set to 5 ms, which is very efficient in analyzing vowel formants (Styler, 2017). Maximum formant settings in PRAAT were adjusted for some vowels and speakers if required. The dynamic range was set at 50 dB. Firstly, the vowels were segmented out of the words. The segmentation of the vowels was done with the help of a series of acoustic cues which were observed in the broadband spectrograms and waveforms.

First, the release burst from a plosive, which marks the onset of a vowel, was pinpointed. Second, since the lack of energy in the spectrogram and the waveform characterizes a plosive, an abrupt increase in energy made it possible to locate the onset of a vowel. Third, a more explicit and consistent formant structure was sought in order to identify the onset of a vowel. Finally, cyclic repetition or periodicity in the waveform helped facilitate the segmentation of the vowels. In addition, in order to be able to locate the offset of a vowel when it is followed by a plosive, the reverse of these acoustic cues was employed. Therefore, the offset of a vowel was determined based upon an abrupt loss of energy in the spectrogram and the waveform, the lack of periodicity and the nonexistence of a regular formant structure.

Figure 32 depicts the segmentation process of the vowel [ɑ] occurring in the word *kar* ‘snow’ pronounced by a male speaker in the study. The top panel represents the waveform. The middle panel shows the spectrogram of the word. A text grid serving as the surface representation of the word is added below these acoustic panels. The burst which appears at the beginning of the waveform is the release of the plosive, preceding the voiced onset time. After the positive VOT, the vowel can be identified with an abrupt increase in energy and cyclic repetition in the waveform along with a more distinct formant structure in the spectrogram. In the same vein, the ending of the vowel can be located. The pronunciation of the word *kar* ‘snow’ lasts approximately 363 ms and the duration of the vowel [ɑ] is 66 ms in Figure 32.

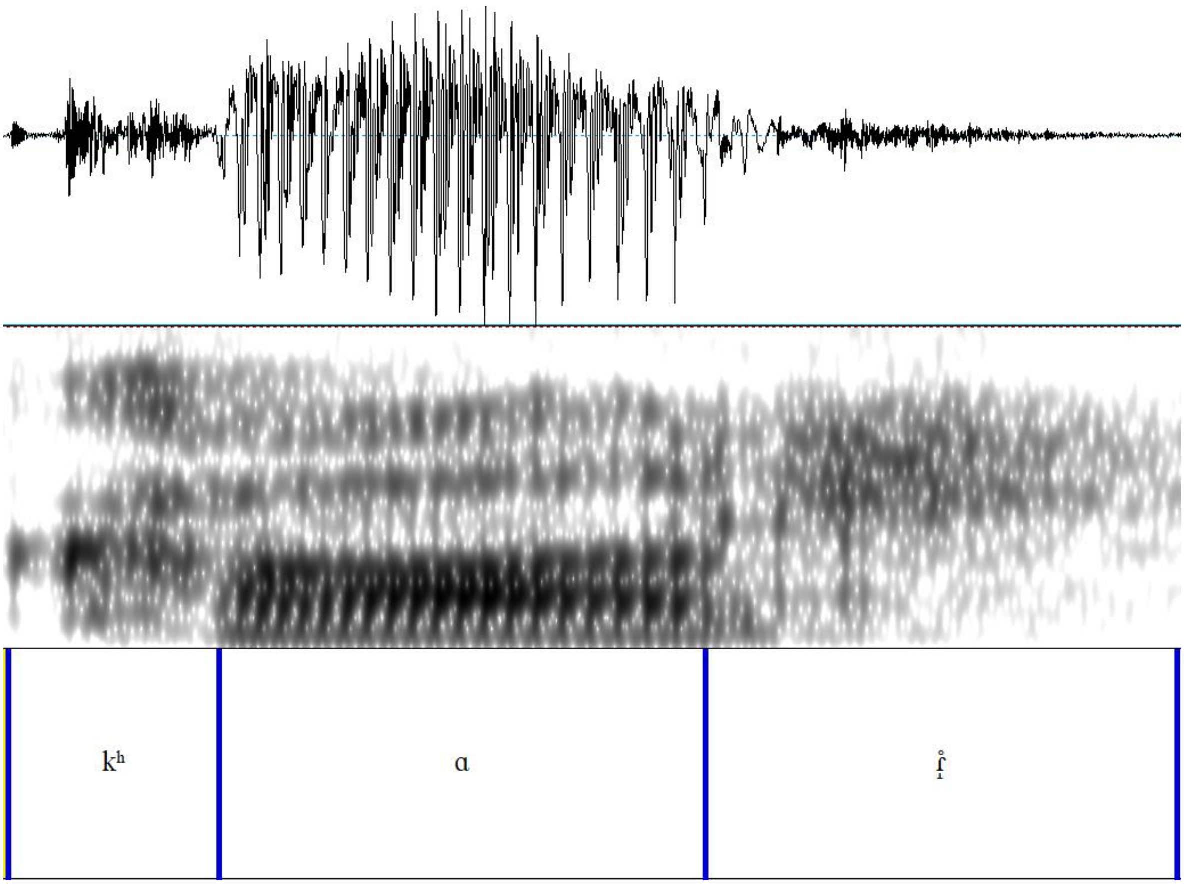


Figure 32. Waveform and the spectrogram of the word *kar* ‘snow’.

Identifying the vowels which were in contact with fricatives required rather different acoustic cues. Given the nature of fricatives, aperiodicity is observed in waveforms in addition to high frequencies seen in spectrograms. Decrease in energy in the waveform and transposition from periodicity to aperiodicity are important signals for fricatives. Similarly, vowels which are in contact with fricatives can be located thanks to the onset of a clear formant structure and a shift from aperiodicity to periodicity. An example can be seen in Figure 32 where a voiceless alveolar tapped fricative [ɾ̞̊] occurs word-finally. The decrease in energy and aperiodicity in the waveform indicate the beginning of the fricative or the end of the vowel. The impact that fricatives have on spectrograms is clearer in Figure 33 which displays the waveform and the spectrogram of the word *suşi* ‘sushi’ pronounced by a female speaker in the study.

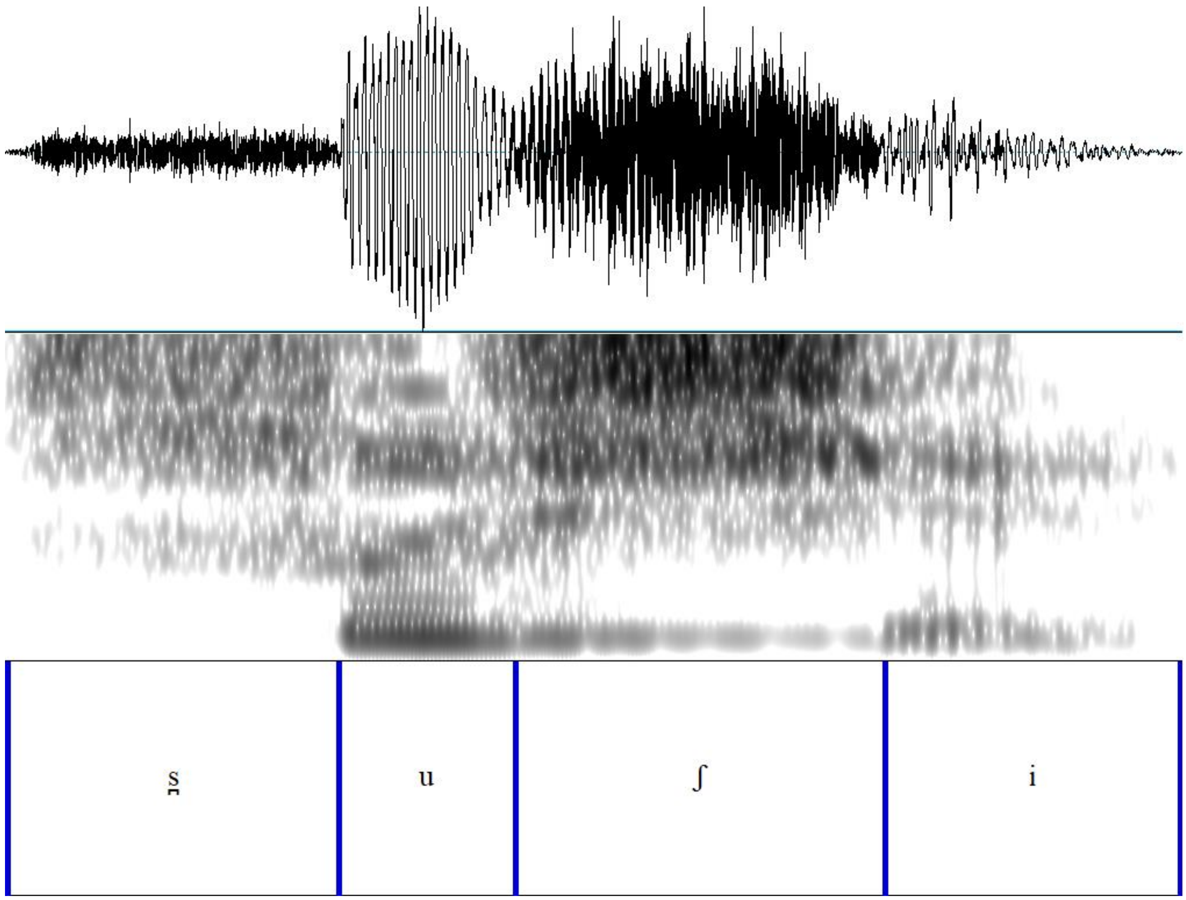


Figure 33. Waveform and the spectrogram of the word *suşi* ‘sushi’.

The fricatives [s̺] and [ʃ] in the spectrogram in Figure 33 appear to have much higher energy in the higher frequencies. The maximum formant frequency is set to 5 kHz in the spectrogram; however, one could still see energy up to 8 kHz if selected. The fricatives surrounding the vowel [u] can easily be detected in the waveform in which the aperiodicity of [s̺] and [ʃ] is evident. In a similar way, [i] is also recognizable following [ʃ] in the spectrogram and the waveform due to the fact that the energy of the former sound is not centered around higher frequencies and a shift occurs from aperiodicity to periodicity.

The segmentation of the vowels in the context of the sonorants was more demanding than the plosives and fricatives due in part to the similar spectral features that sonorants and vowels share. Similar to vowels, sonorants also display periodicity and a high degree of intensity in the waveform and tend to have an apparent formant structure in the spectrogram. Nasals are articulated by lowering the velum so that the airstream goes out through the nasopharynx. Therefore, they will introduce additional resonances from the nasal cavity and this nasal resonance obscures the vocalic formants (Fry, 2012; Zsiga, 2013). As a result, two significant effects can be observed in spectrograms: firstly, the peak of energy which is created by the first formant happens to be at a lower frequency for the duration of the nasal consonant than of the vowel and secondly, the high level of energy of F_2 of the vowel drops to a substantially low energy for any neighboring nasal. The spectrogram and the waveform of the word *nöron* ‘neuron’ articulated by a female speaker in the study are shown in Figure 34 in which two nasal consonants can be seen. The effects that are mentioned above are very beneficial in detecting the nasals. First, the word-initial nasal consonant can be identified with the help of the very low F_1 which appears to increase at the onset of the vowel. In addition, both the word-initial and word-final nasal consonants are observed to muddy the vocal formants.

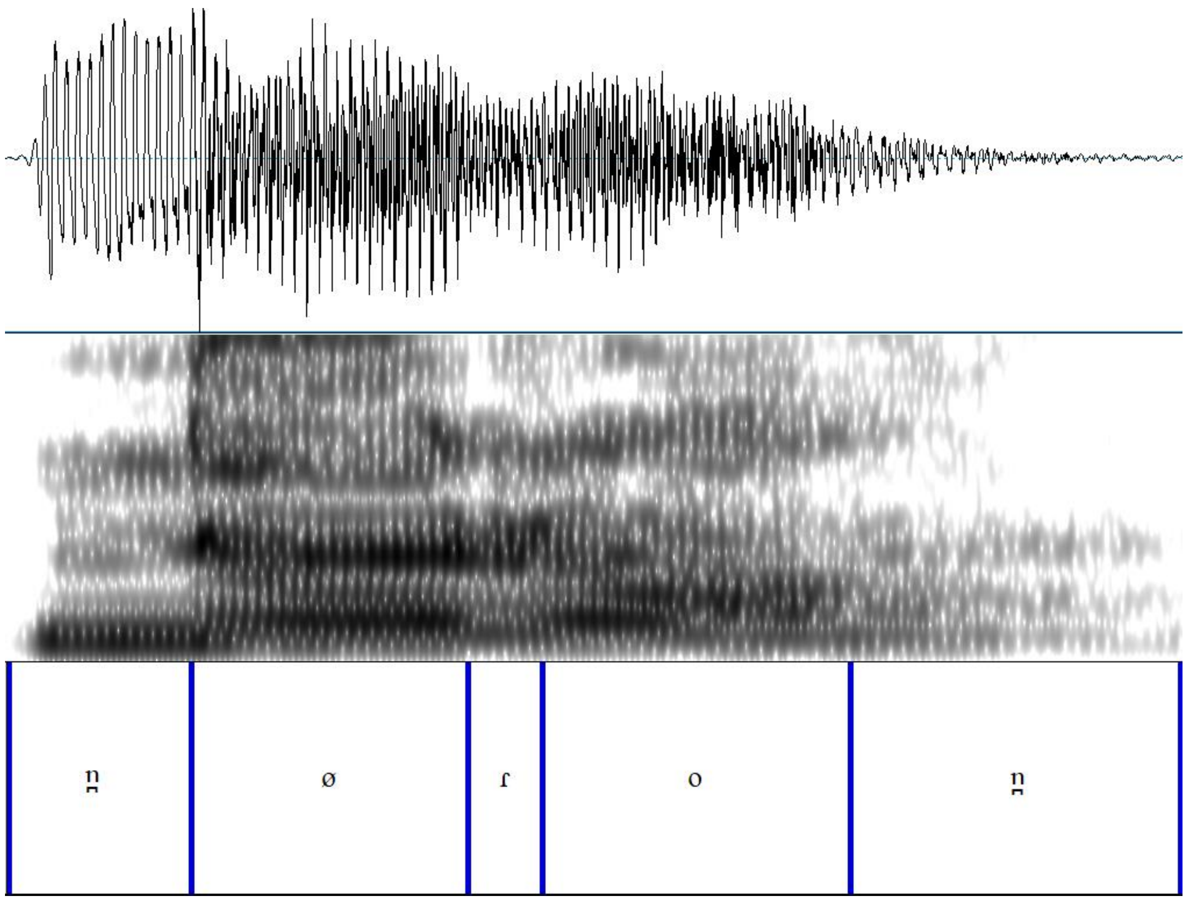


Figure 34. Waveform and the spectrogram of the word *nöron* ‘neuron’.

[ɾ̝̊] and [ɾ] are the rhotic consonants in Turkish. [ɾ̝̊] surfaces at the end of a word while [ɾ] appears elsewhere. Figure 32 presents an example for the former sound; however, the behavior of [ɾ̝̊] reflects that of fricatives rather than rhotics. On the other hand, as taps are defined by a rapid movement of the tongue to the alveolar ridge, a brief silence is generally noticeable in spectrograms. Furthermore, this silence can also be accompanied by a short decrease in intensity, which is somewhat noticeable in Figure 34. A lucid example for [ɾ] is presented in Figure 35 which has the waveform and the spectrogram of the word *virüs* ‘virus’ pronounced by a male speaker in the study. [ɾ] in Figure 35 shows a short decrease in energy in the waveform after [i] and then periodicity is observed due to [y]. Additionally, a brief silence, which is the result of the closure caused by the contact between the tongue and the alveolar ridge, is seen in the spectrogram for the duration of [ɾ].

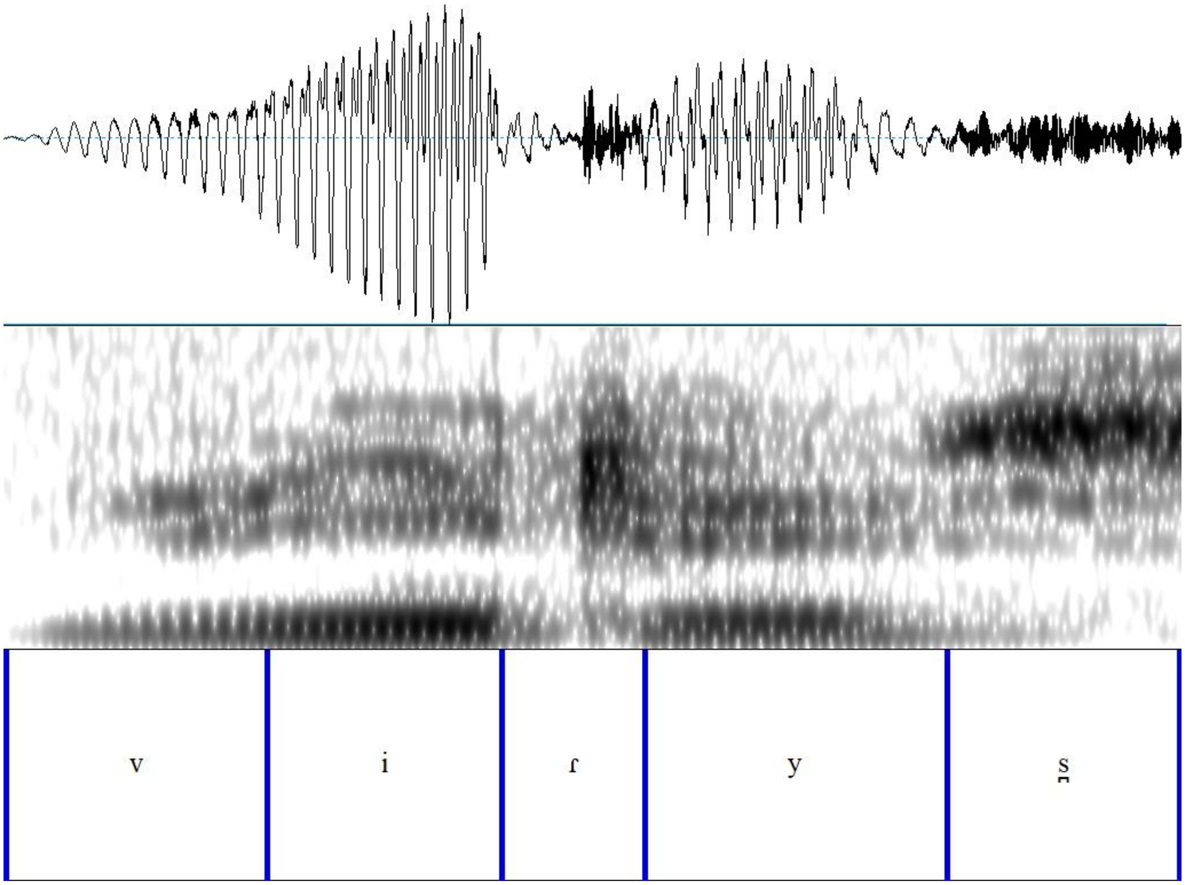


Figure 35. Waveform and the spectrogram of the word *virüs* ‘virus’.

Finally, we can observe two lateral consonants in the phonetic inventory of Turkish, namely [l] and [ɫ̪]. The former is an alveolar lateral while the latter is a velarized dental lateral. They are two distinct phonemes, that is, they can be found in minimal pairs such as *sol* ‘musical note g’ and *sol* ‘left’. Both of these words were articulated by the participants in the study. Figure 36 and Figure 37 depict the waveform and the spectrogram for [l] and [ɫ̪] respectively. Notice that F_2 values of the non-velarized alveolar lateral tend to be much higher than those of the velarized dental lateral (Börtlü, 2020; Recasens & Espinosa, 2005). Therefore, F_2 is decisive in distinguishing the laterals from the vowel. [l] in Figure 36 demonstrates that F_2 rises after the vowel.

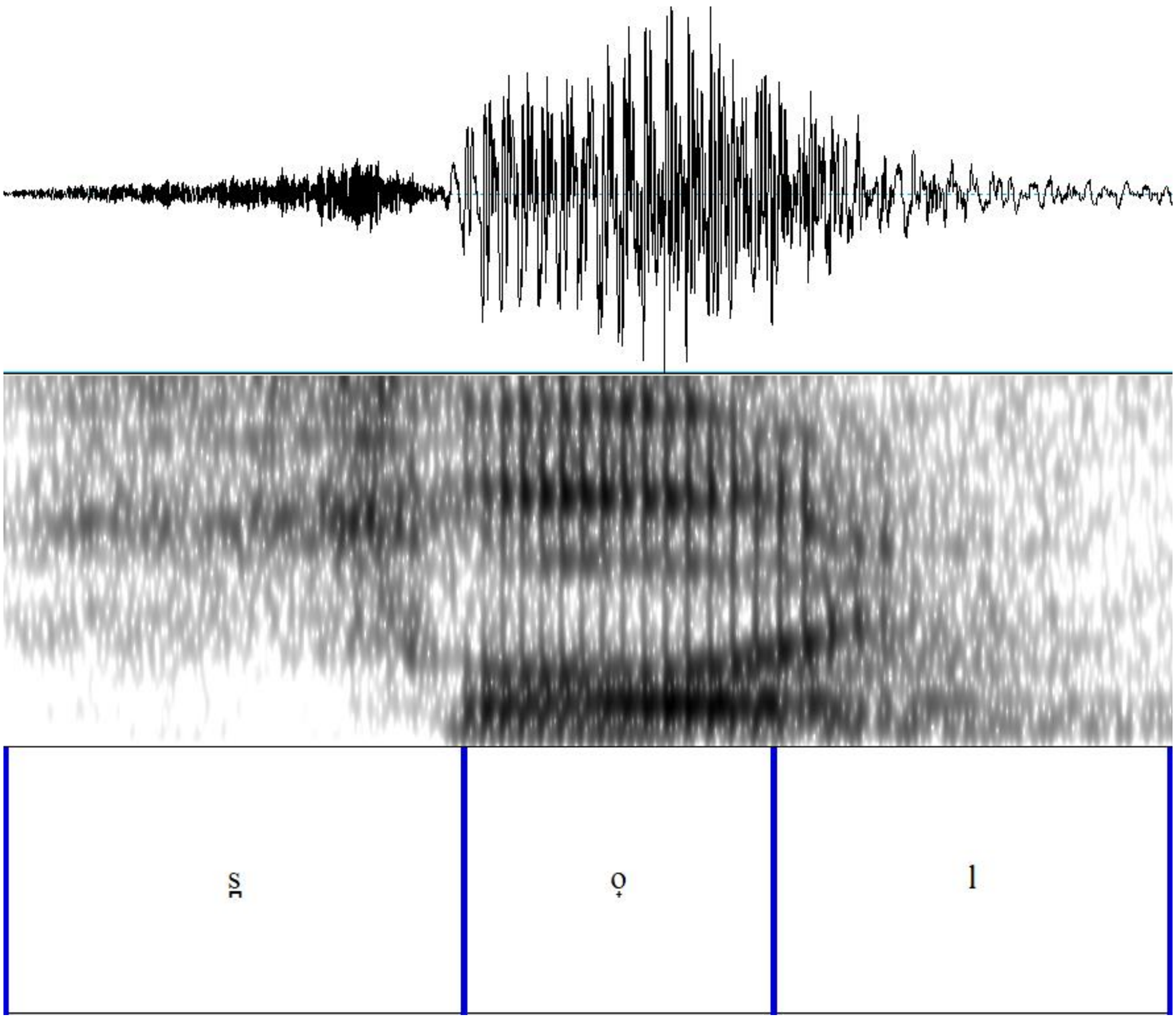


Figure 36. Waveform and the spectrogram of the word *sol* ‘musical note g’.

On the other hand, F_2 of the velarized dental lateral behaves very differently than that of the non-velarized alveolar lateral. F_2 of the lateral consonant in Figure 37 appears to be much lower when compared to that of its non-velarized counterpart.

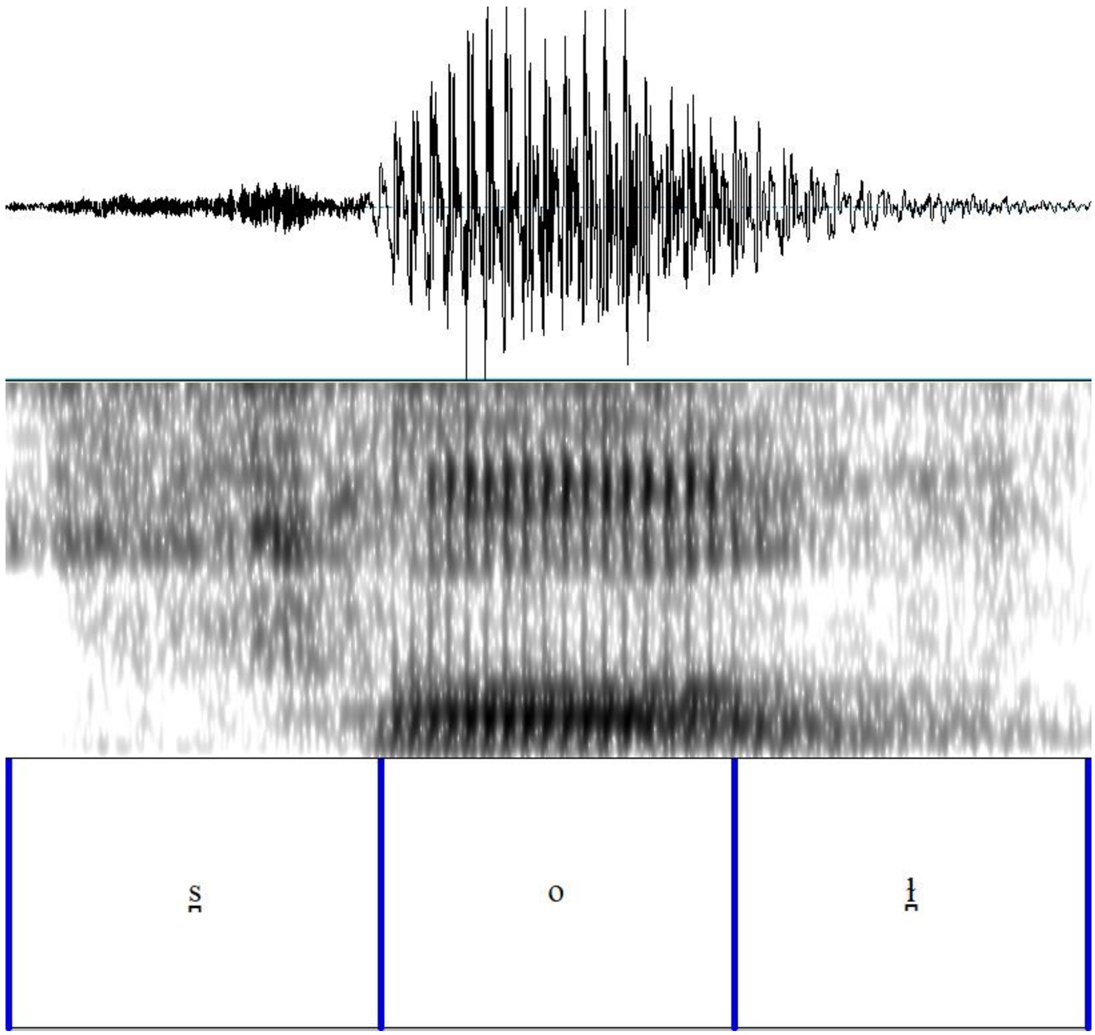


Figure 37. Waveform and the spectrogram of the word *sol* ‘left’.

To sum up, various acoustic cues were utilized in order to determine the onset and offset of the vowels. The acoustic cues that were used depended upon the characteristics of the segmental context surrounding the vowels. If the vocalic segments that were under scrutiny were not distinguishable despite acoustic cues, they were marked as “in dispute” and excluded from the analysis. Out of a total of 960 vocalic segments articulated by 10 speakers, five males and five females, 29 vowels were excluded since the segmentation process was unclear.

After the segmentation, the formant frequencies of the vowels were obtained at the midpoint of their duration. The reason why the midpoint is chosen is that it is the farthest removed from the neighboring consonants. Therefore, the formants of the vowels will be less susceptible to the effects of coarticulation from the surrounding consonants.

As the size of the vocal tract changes remarkably for females and males, the frequency ranges obtained from their vowels inherently differ. In studies where the speech of female and male speakers is examined, it is of great importance to reduce interspeaker vowel variability (Johnson, 1990). The Lobanov (1971) method of normalization was used since it performs better than other normalization methods in that it reduces physiological variation between speakers more reliably (Adank, Smits, & van Hout, 2004; Aydın & Uzun, 2020).

CHAPTER 4

FINDINGS AND DISCUSSION

4.1 DISCUSSION OF THE FINDINGS

4.1.1 Acoustic Properties of Turkish Vowels

The mean F_1 and F_2 values of the vowels for ten speakers, who identified themselves as five males and five females, are provided separately for each vowel in Table 18 and Table 19. The first half of the speakers (i.e. Speaker A, B, C, D and E) in Table 18 are female while the other half (i.e. Speaker F, G, H, I and J) in Table 19 are male. The mean values are all in Hertz and rounded off to the nearest whole number. All the analysis in this section was conducted in RStudio (RStudio Team, 2019) and the graphical representations were created thanks to the package phonR (McCloy, 2016).

Table 18. Mean F_1 and F_2 values of the vowels for female speakers (in Hertz).

		a	**ɑ**	**e**	**ɛ**	**ɯ**	**i**	**o**	**ọ**	**ø**	**u**	**ụ**	**y**
Speaker A	F_1	962	800	595	732	426	398	540	627	552	400	409	370
	F_2	1643	1541	2119	1721	1693	2647	1130	1212	1669	1022	1233	1969
Speaker B	F_1	818	895	627	878	536	501	645	645	612	544	463	471
	F_2	1616	1402	2215	1719	1713	2596	1193	1134	1767	1283	1277	1942
Speaker C	F_1	985	768	594	840	448	370	499	623	562	373	420	388
	F_2	1651	1522	2184	1790	1747	2552	1019	1155	1687	905	1240	1912
Speaker D	F_1	740	742	456	748	396	382	470	509	461	379	378	365
	F_2	1576	1344	2092	1802	1478	2248	1102	1240	1592	1077	1162	1768
Speaker E	F_1	711	731	558	642	442	483	535	499	484	482	472	460
	F_2	1424	1306	2075	1733	1456	2196	1186	1299	1671	989	1105	1858

Table 19. Mean F_1 and F_2 values of the vowels for male speakers (in Hertz).

		a	ɑ	e	ɛ	ɯ	i	o	ọ	ø	u	ụ	y
Speaker F	F_1	733	629	522	739	365	278	451	474	469	324	342	285
	F_2	1347	1165	1779	1548	1387	2018	828	940	1370	886	1102	1694
Speaker G	F_1	565	551	524	595	421	416	506	469	483	412	414	377
	F_2	1242	963	1750	1639	1340	1861	828	1198	1547	853	1194	1615
Speaker H	F_1	707	690	467	668	327	341	479	503	447	360	378	311
	F_2	1355	1237	1923	1607	1385	2234	1112	1202	1422	984	1040	1651
Speaker I	F_1	645	594	446	503	386	328	421	447	416	369	403	363
	F_2	1324	1144	1868	1583	1346	1998	1033	1025	1449	1041	988	1662
Speaker J	F_1	679	662	509	619	389	327	474	495	458	428	405	360
	F_2	1312	1202	1796	1532	1290	2032	1043	1093	1396	1042	1176	1526

Table 18 and Table 19 help examine the individual formant frequencies for all the participants. In addition, Table 20 shows the mean F_1 and F_2 values for all the male and female speakers. Therefore, the differences between genders are made more explicit in Table 20. Again, the mean F_1 and F_2 values are all given in Hertz and rounded off to the nearest whole number.

Table 20. Mean F_1 and F_2 values of the vowels for female and male speakers (in Hertz).

		a	ɑ	e	ɛ	ɯ	i	o	ọ	ø	u	ụ	y
Female speakers	F_1	843	792	569	768	450	427	538	579	534	435	427	411
	F_2	1582	1431	2136	1753	1612	2448	1126	1210	1677	1058	1202	1890
Male speakers	F_1	668	625	494	625	377	338	466	478	455	379	386	338
	F_2	1318	1142	1824	1582	1349	2034	969	1086	1437	959	1096	1635

The mean values for female and male speakers in Table 20 are plotted in Figure 38 and Figure 39 respectively. The vowels are separately colored in both plots. The vowel means are marked by their own symbols in bold while all the vowel tokens are made semi-transparent in order to improve visualization. The y-axis represents F_1 and the inverted x-axis corresponds to F_2. All the values are provided in Hertz.

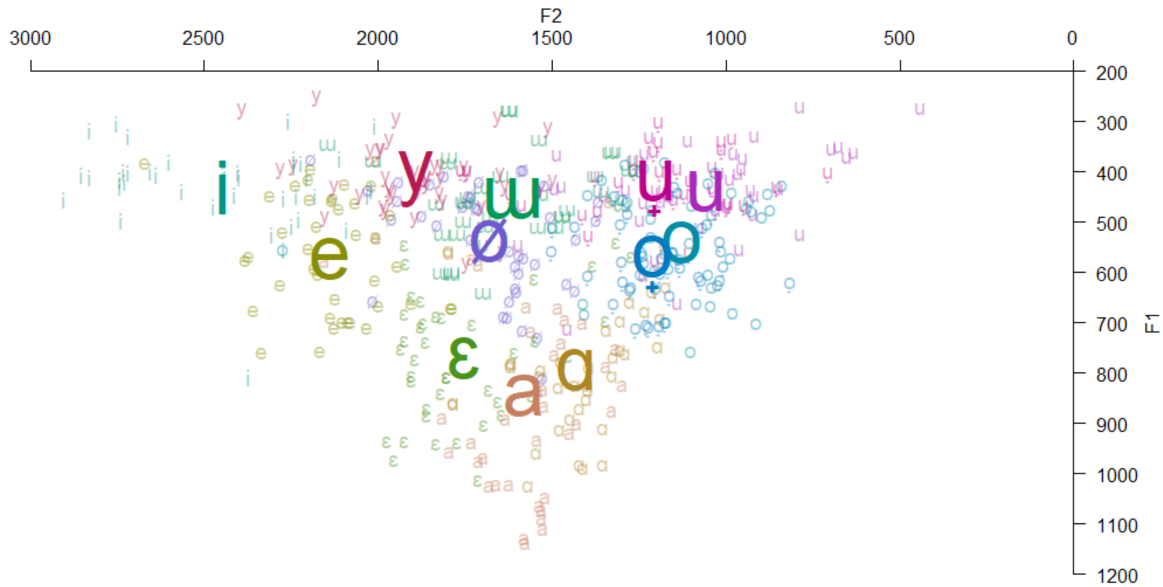


Figure 38. Vowels of female speakers (F_1 and F_2 values in Hertz).

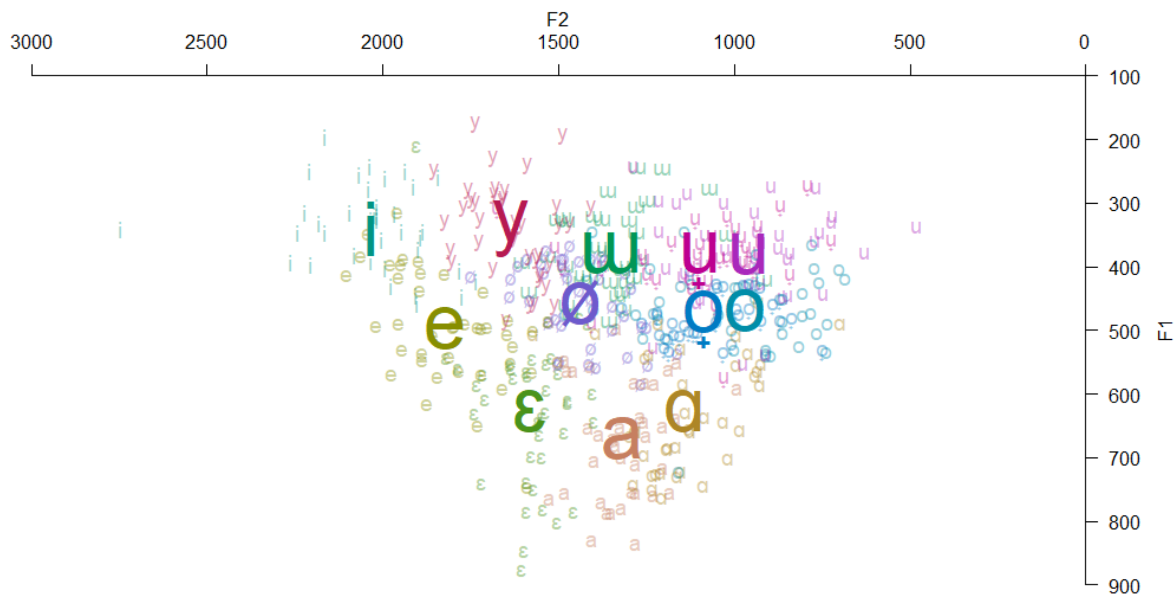


Figure 39. Vowels of male speakers (F_1 and F_2 values in Hertz).

These vowel plots are informative; however, it seems that there are overlaps in Figure 38 and Figure 39 since they include different speakers. This visual clutter can be reduced to some extent with the help of roughly 68% confidence ellipses, which equal to ±1 standard deviation on the normal density contour estimated from the data. The ellipses are drawn in the location of the mean of each vowel seen in Figure 38 and Figure 39.

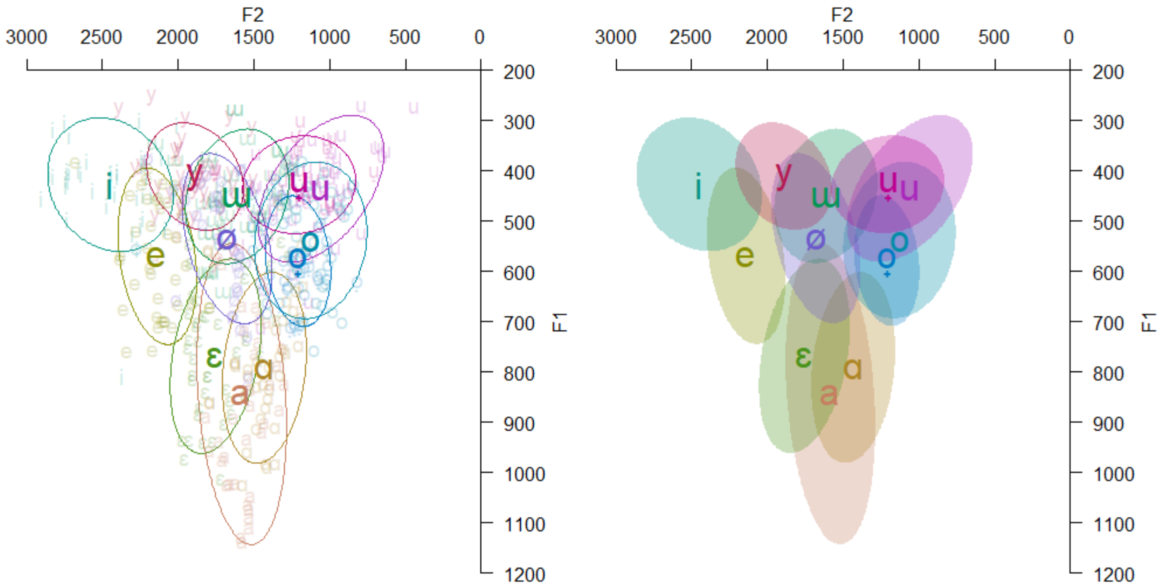


Figure 40. Vowels of female speakers with approximately 68% confidence ellipses.

In Figure 40, approximately 68% confidence ellipses are drawn for both of the vowel plots. The ellipses on the left are filled in and presented on the right. Moreover, the individual vowel tokens are removed for the plot on the right. The same procedure is followed for the vowels of the male speakers as represented in Figure 41.

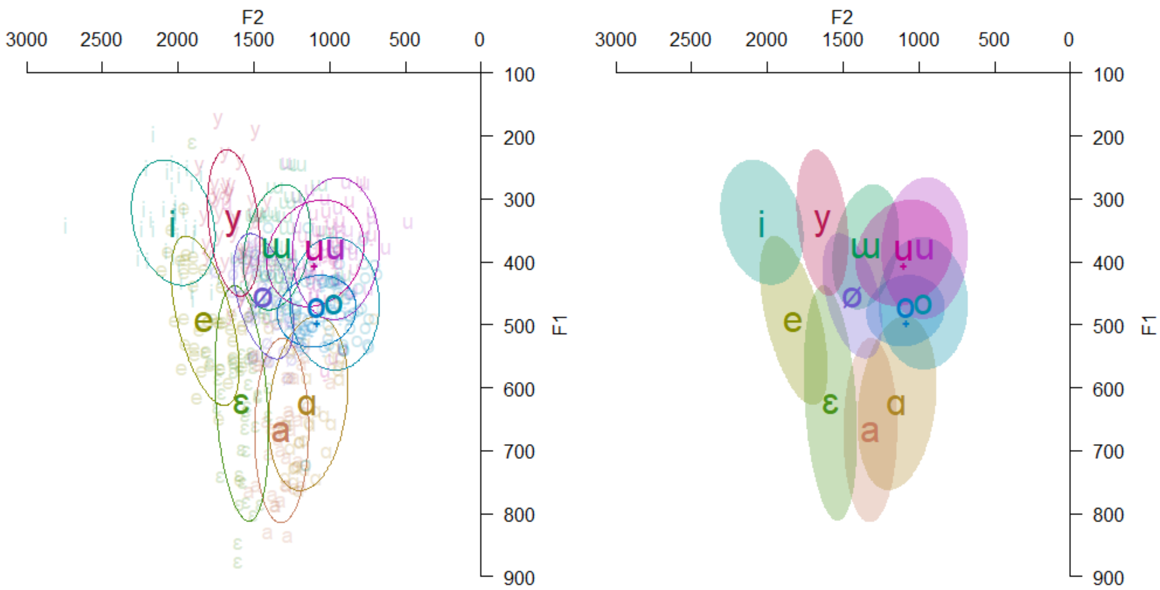


Figure 41. Vowels of male speakers with approximately 68% confidence ellipses.

The vowel spaces of both genders are presented with convex hulls in Figure 42. The boundary lines are drawn according to the farthest vowels which are [i u a]. The plot is color-coded for gender, that is, the vowels of the male speakers are in red whereas those of the female participants are marked by green.

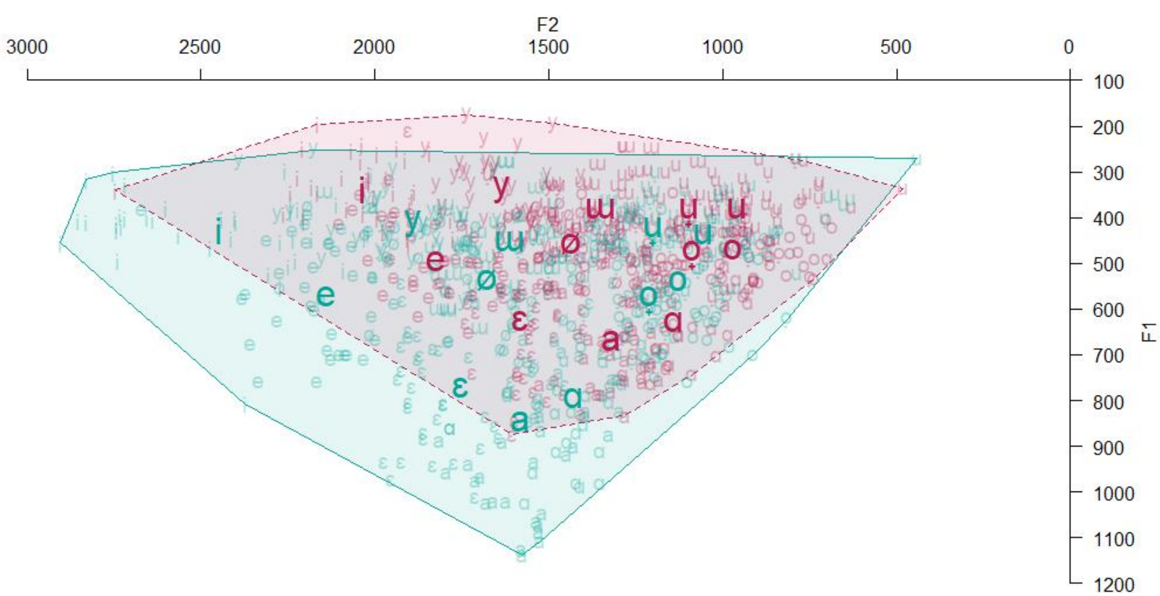


Figure 42. Vowel space of both genders with convex hulls.

(green for female and red for male).

4.1.1.2 Vowel Triangle of Turkish

The Lobanov (1971) method of normalization was utilized on the vowels. According to Adank, Smits and van Hout (2004), the Lobanov method seems to be the best compared to other normalization methods. In this method, formant values of each speaker are put on a scale of standard deviations. The Lobanov method, which uses z-score, is calculated with the following formula:

$$\frac{F_n - \mu(F_n)}{\sigma(F_n)}$$

Fn is the formant *n* of a vowel. *μ(Fn)* is the mean value for the formant *n* for the participant in question and *σ(Fn)* is the standard deviation for the formant *n* of the participant. All the normalized vowel formants of all the speakers are provided in Figure 43. Each vowel is given a different color.

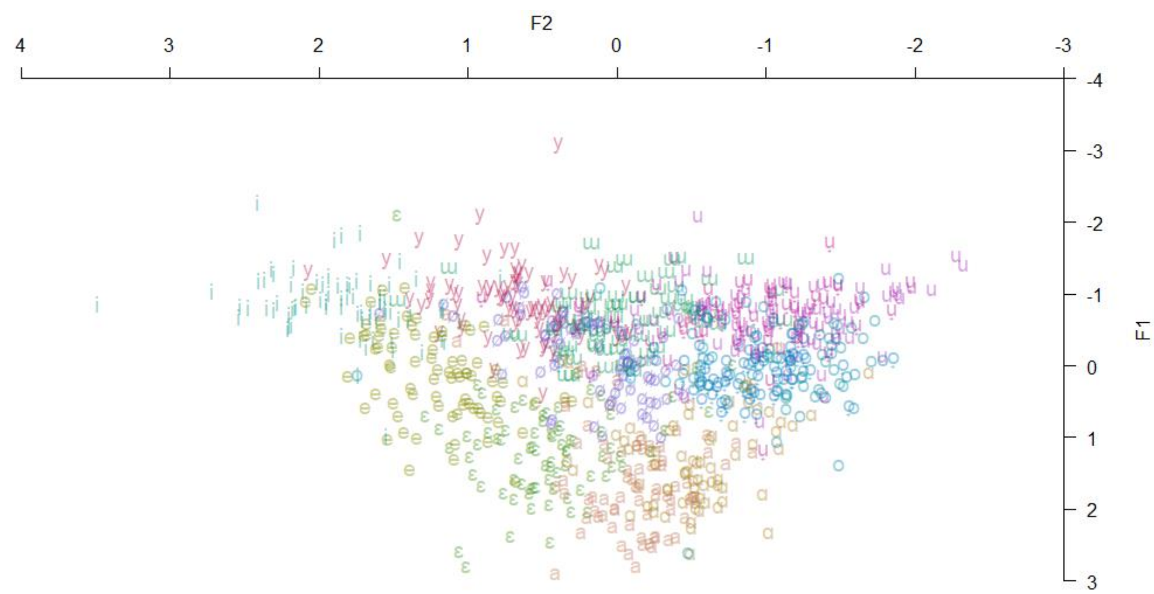


Figure 43. Normalized vowel formants for all the speakers.

Approximately 68% confidence ellipses are drawn in the location of the mean of each vowel for the normalized vowel plot which can be seen in Figure 44. The ellipses are filled in and the normalized vowel tokens can also be seen in addition to the means.

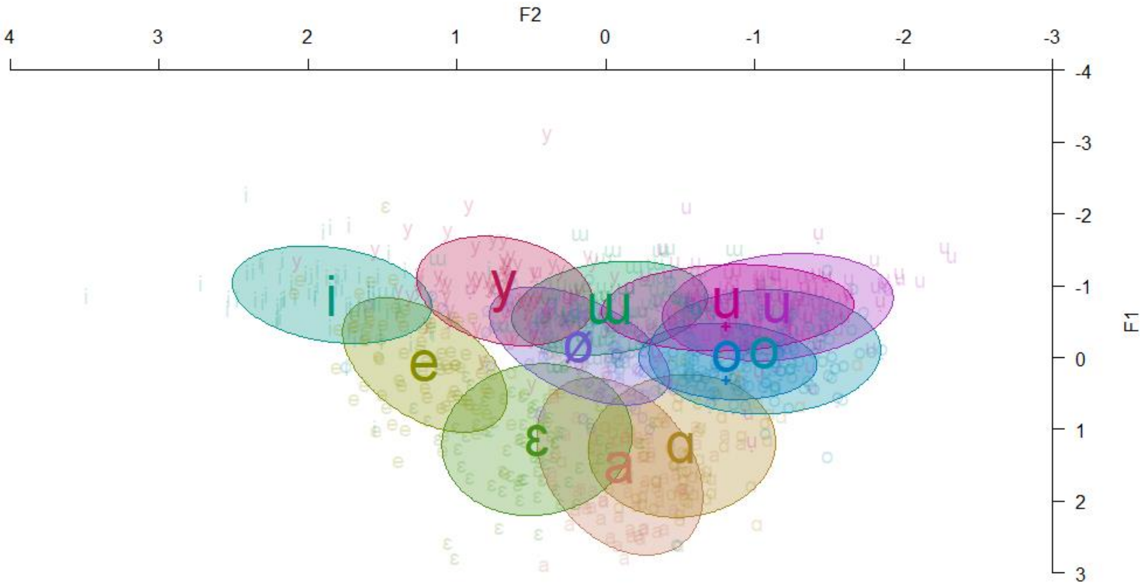


Figure 44. Normalized vowel formants for all the speakers with approximately 68% confidence ellipses.

Figure 45 presents the plot of only the means of the normalized vowel formants without any ellipses and individual vowel tokens. The values on the x-axis and y-axis are removed and the sizes of the symbols are reduced.

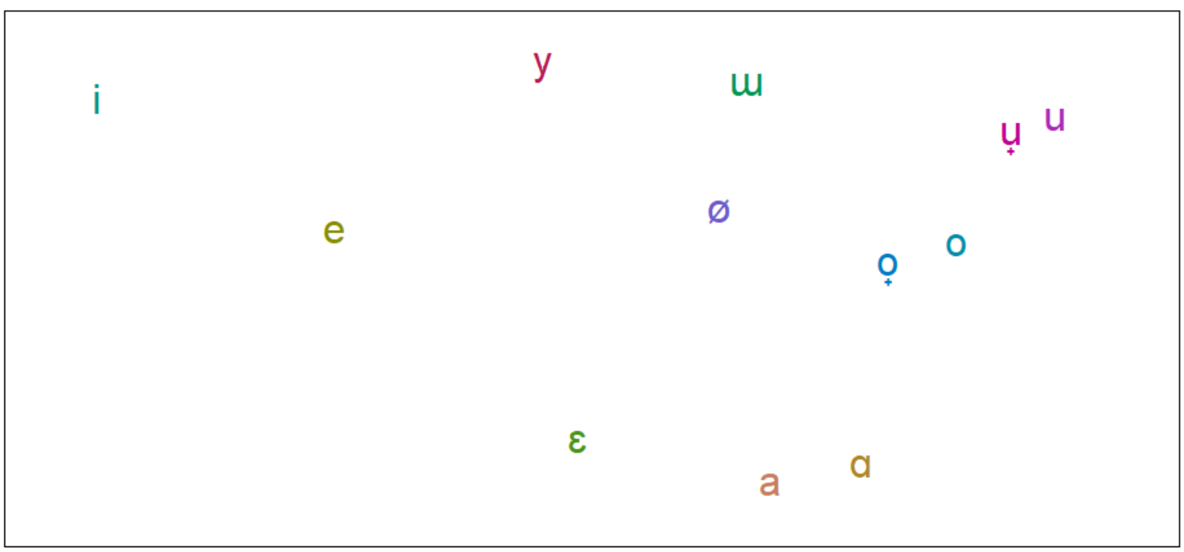


Figure 45. Means of the normalized vowel formants for all the speakers.

Although the vowel inventory of Turkish is provided in the previous figures, the vowels seem to be somewhat disorganized. Therefore, as it is one of the aims of this study, a reference vowel chart needs to be provided. The vowel triangle of Turkish in Figure 46 is arrived at with the addition of connecting lines as a visual aid. Also, the vowel symbols are adjusted to increase equal spacing.

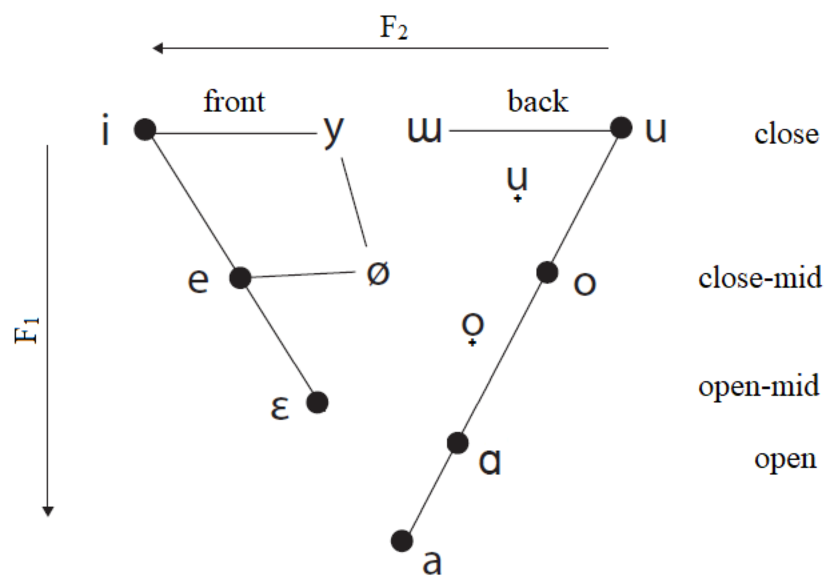


Figure 46. Vowel triangle of Turkish.

The acoustically realistic plot in Figure 45 is converted into a reference chart, the stylization of which resembles the tongue quadrilateral of the IPA. However, Figure 46 is based upon “acoustic fact” than “physiological fantasy” in Russell’s (1928) words. The idea of such a triangular shape is in sympathy with Lindsey (2017) who proposed using a universal triangular vowel chart instead of the traditional IPA vowel quadrilateral. In Figure 46, the vowels are connected with lines and those on the periphery and their horizontal neighbors differ in rounding in that those to the right are rounded. The chart preserves the typical descriptive specifications of ‘backness,’ ‘closeness’ and ‘rounding’ which are generally used by phonologists.

4.1.2 Phonology of Turkish Vowels

4.1.2.1 Turkish Vowel Phonemes

Eight vowels are in contrast with each other in standard Turkish, that is, there are eight distinct vowel phonemes in the language. Allophones of these phonemes will be mentioned in Section 4.1.2.2 after the examination of vowel phonemes. Firstly, we should have a look at contrasting vowel sounds in Turkish, which can be demonstrated as in the following minimal pair paradigm:

k**i**r – k**e**r – k**ü**r – k**ö**r – k**ı**r – k**a**r – k**u**r – k**o**r

All of the meaningful words above have exactly the same phonemes except for the bold vowel sounds in the middle (i.e. /i/, /e/, /y/, /ø/, /ɯ/, /ɑ/, /u/ and /o/ respectively). Each different vowel changes the meaning of the words even if we keep the other sounds intact, which makes all these eight vowels sounds **distinct phonemes**. Height, backness and rounding are contrasting features that determine the difference among the Turkish vowel phonemes. These phonemes are shown below in minimal pairs with respect to height feature.

height contrast:	[+high]		[-high]	
	is	[is̪]	es	[es̪]
	gül	[ɟyl]	göl	[ɟøl]
	tın	[t̪ʰɯn̪]	tan	[t̪ʰɑn̪]
	kul	[kʰuɫ̪]	kol	[kʰoɫ̪]

As can be seen, the vowels in all the minimal pairs above have contrast only in height feature but have the same features of backness and rounding. For instance, the vowels [ɯ] and [ɑ], in the minimal pair *tın* and *tan* respectively, are both [-round] and [+back] but differ only in [±high] feature. Similarly, [y] and [ø], in *gül* and *göl* respectively, are [-back] and [+round], however they differ in height feature, that is, the former is [+high], while the latter is [-high]. Additionally, [i] and [e], in *is* and *es* respectively, are both unrounded and front vowels despite differing in height feature. Lastly, the vowel phonemes [u] and [o], in *kul* and *kol* respectively, share the features [+round] and [+back] in spite of differing only in [±high] feature.

backness contrast:	[-back]		[+back]	
	seç	[s̪etʃʰ]	saç	[s̪ɑtʃʰ]
	kin	[kʰin̪]	kın	[kʰɯn̪]
	üç	[ytʃʰ]	uç	[utʃʰ]
	ön	[øn̪]	on	[on̪]

The vowels shown in the minimal pairs above are different from each other only in their [±back] feature but have exactly the same height and rounding features. To give an example, [i] and [ɯ] in *sin* and *sın* are both [+high] and [-round]; however, they differ in +/- value of their backness features. Similarly, [e] and [ɑ], seen in *seç* and *saç* respectively, both share the features [-high] and [-round], but they differ in [±back] feature. In addition, [y] and [u], in *üç* and *uç* respectively, are both [+high] and [+round], however, they differ in backness feature, that is, the former is [-back] while the latter is [+back]. Finally, [ø] and [o], present in *ön* and *on* respectively, are both [-high] and [+round] despite differing in backness feature.

rounding contrast:	[+round]		[-round]	
	üç	[ytʃʰ]	iç	[itʃʰ]
	göç	[ɟøtʃʰ]	geç	[ɟeʃʰ]
	kul	[kʰuɫ̪]	kıl	[kʰɯɫ̪]
	ok	[okʰ]	ak	[ɑkʰ]

The minimal pairs above demonstrate the same tradition, in which the vowel pairs only differ in +/- value of their rounding feature while they agree in height and backness features. For instance, [o] and [ɑ], in *ok* and *ak* respectively, are both [+back] and [-high] while the former is [+round] and the latter [-round]. [u] in *kul* is [+round] while [ɯ] in *kıl* is [-round]; however, they both have the same [+back] and [+high] values. Additionally, [ø] and [e], in *göç* and *geç* respectively, are both [-high] and [-back] but they differ only in [±round] feature. Lastly, [y] and [i], in *üç* and *iç* respectively, both have the features [+high] and [-back]; however, the former is [+round] while the latter is [-round].

To put it briefly, eight vowel phonemes can be categorized in terms of three distinctive features. To summarize, a contrasting feature matrix of Turkish vowel phonemes can be arranged as in Table 21.

Table 21. Distinctive feature matrix of Turkish vowel phonemes.

	i	e	y	ø	ɯ	ɑ	u	o
back	-	-	-	-	+	+	+	+
high	+	-	+	-	+	-	+	-
round	-	-	+	+	-	-	+	+

4.1.2.2 Turkish Vowel Allophones and Phonological Rules

4.1.2.2.1 Vowel Fronting in Turkish

Apart from the allophones which are chosen as the basic phonemes (i.e. [ɑ e ɯ i o ø u y]), four different allophones of eight phonemic vowels are also present in the phonetic inventory of Turkish, namely [u̟], [o̟], [a] and [ɛ]. The diacritics below the first two allophones denote slight fronting of the sounds. As no minimal pairs are observed between back vowels and their fronted counterparts, [u̟], [o̟], and [a] are not distinct phonemes. Quite the contrary, data show that they are in a **complementary distribution**, in which the fronted back vowels occur before or after the alveolar lateral [l] or a palatal plosive [cʰ ɟ] in the same syllable, e.g. *ulvi* [u̟lvi], *loş* [lo̟ʃ] and *kâğıt* [cʰaɯt̪ʰ].

The Turkish writing system is generally considered to be a fairly reliable means of identifying sounds. For instance, contrary to English where the letter ‘c’ can be /s/ as in *cell* or /k/ as in *call*, the same letter is invariably transcribed as /dʒ/ as can be seen in *ceket* ‘jacket,’ *cop* ‘nightstick’ or *cahil* ‘ignorant’ in Turkish at the phonemic level. However, it should be noted that the Turkish orthography does not give as many clues as it is thought when it comes to laterals (i.e. /l/ and /ɫ̠/) and palatal plosives (i.e. /c^h/ and /ɟ/). Occasionally, the circumflex ‘^’ can be placed over some vowels to mark fronting, e.g. *gâvur* ‘infidel,’ *kâr* ‘profit,’ *hâl* ‘condition,’ etc. In addition, it can also be used to denote long vowels, e.g. *âlem* ‘universe,’ *âdet* ‘custom.N,’ *âşık* ‘lover,’ etc. A circumflex can even have an effect on both lengthening and fronting of vowels as in *hâlâ* ‘yet,’ *kâse* ‘bowl’ and *hikâye* ‘story’. Furthermore, Turkish has words in which vowels may undergo fronting even though they do not have the circumflex over them. For example, fronting occurs in the letter <a> in *kalp* ‘heart,’ *lacivert* ‘navy blue’ and *helal* ‘halal’. Also, vowels in Turkish can be long without the circumflex as in the words *katil* ‘murderer,’ *muhabir* ‘reporter,’ *cahil* ‘ignorant’ and *siyaset* ‘politics’ where the letter <a> is long. Therefore, the circumflex mark does not appear to provide a consistent way of pronouncing vowels.

The distribution of [a] and [ɑ] can be observed in Table 22 which demonstrates that the two sounds are in complementary distribution. The distribution of [a] is very limited compared to [ɑ] whose environment is defined by “elsewhere”. [ɑ] is chosen as a phoneme since its environment is more diverse than that of [a]. C_0 in Table 22 marks zero or more consonants.

Table 22. Distribution of [ɑ] and [a] in Turkish.

	$\$\text{l}\_\_\_,\ \$\text{c}^{h}\_\_\_,\ \$\text{ɟ}\_\_\_,\ \_\_\_\text{lC}_0\$$	elsewhere
[a]	l*a*net, k*â*hin, g*â*vur, k*a*lp	
[ɑ]		l*a*l*a*, *ka*tı, g*a*r, kur*a*l

Consequently, the allophones of /ɑ/ can be represented as follows:

```
      /ɑ/
     /   \
  [a]     [ɑ]
```

The fronting of /ɑ/ can be expressed by rule:

Fronting of /a/ in Turkish

$$\text{ɑ} \rightarrow \text{a} \,/\, \left\{ \begin{array}{l} \$ \left\{\begin{array}{c} \text{l} \\ \text{c}^{\text{h}} \\ \text{ɟ} \end{array}\right\} \_\_\_ \\ \_\_\_ \left\{\begin{array}{c} \text{l} \\ \text{c}^{\text{h}} \\ \text{ɟ} \end{array}\right\} C_0\ \$ \end{array} \right\}$$

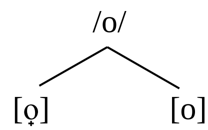
The environments seen in the rule above are more comprehensive than Table 22. For example, it has been found that /ɑ/ does not precede /ɟ/ at the end of a syllable in Turkish. However, this environment is included in the rule since /ɑ/ is expected to undergo fronting if it ever occurs in such an environment, for instance in case of new neologisms. This procedure is followed for the other back vowels as well for the sake of comprehensiveness.

The distribution of [o] and [o̦] is demonstrated in Table 23. [o̦] and [o] seem to be in complementary distribution. As in the case of [a] and [ɑ], we again choose [o] to be the basic phoneme since it has a much richer environment than [o̦].

Table 23. Distribution of [o] and [o̦] in Turkish.

	$\$l\_\_\_,\ \_\_\_lC_0\$$	elsewhere
[o̦]	l*o*r, g*o*l	
[o]		s*o*ru, d*o*ndurma, av*o*kad*o*, bany*o*, *o*bur

Therefore, one can represent the allophones of /o/ as such:



The fronting of /o/ can be illustrated by rule:

Fronting of /o/ in Turkish

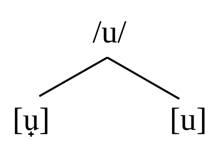
$$o \rightarrow o̟ \;/\; \left\{ \begin{array}{l} \$ \left\{ \begin{array}{c} l \\ c^h \\ \text{ɟ} \end{array} \right\} \_\_\_ \\ \_\_\_ \left\{ \begin{array}{c} l \\ c^h \\ \text{ɟ} \end{array} \right\} C_0 \; \$ \end{array} \right\}$$

The high back rounded vowel /u/ also undergoes a similar process. Table 24 shows the distribution of [u] and [u̟]. The environments where [u̟] occurs appear to be very restricted when compared to [u]. For this reason, [u] is designated as the phoneme rather than [u̟].

Table 24. Distribution of [u] and [u̟] in Turkish.

	$l___, $c^h___, ___lC_0$	elsewhere
[u̟]	l*u*napark, sük*u*net, f*u*l	
[u]		k*u*ral, *u*sta, k*uru*, b*u*gün, ş*uu*r

As a result, the allophones of /u/ can be illustrated as follows:



This alternation can be predictable by rule:

Fronting of /u/ in Turkish

$$u \rightarrow \underset{+}{u} \ / \left\{ \begin{array}{l} \$ \left\{ \begin{array}{c} \text{l} \\ c^{h} \\ \text{ɟ} \end{array} \right\} \_\_\_ \\ \_\_\_ \left\{ \begin{array}{c} \text{l} \\ c^{h} \\ \text{ɟ} \end{array} \right\} C_0 \ \$ \end{array} \right\}$$

The alternations demonstrated above can be expressed with the help of a general vowel fronting rule below:

Vowel fronting in Turkish (preliminary)

$$\begin{array}{c} V \\ [+\text{back}] \end{array} \rightarrow \underset{+}{V} \ / \left\{ \begin{array}{l} \$ \ C_0 \left\{ \begin{array}{c} \text{l} \\ c^{h} \\ \text{ɟ} \end{array} \right\} \_\_\_ \\ \_\_\_ \left\{ \begin{array}{c} \text{l} \\ c^{h} \\ \text{ɟ} \end{array} \right\} C_0 \ \$ \end{array} \right\}$$

This rule seems unsatisfactory and cumbersome, to say the least. The reason is that the environment needs to be repeated in a mirror image string. A solution has been found for such rules, in which the percent sign (%) replaces the traditional slash (/). The percent sign (%) indicates that the rule applies to the string as it is written and to the mirror image of the same string (Jensen, 2004). It should be noted that the general vowel fronting rule in Turkish involves C_0 in both of the environments although this was not the case in the alternations of /ɑ/, /o/ and /u/. As a matter of fact, Turkish does not allow consonant clusters at the beginning of a syllable. Even though there are loanwords in Turkish beginning with two consonants such as *tren* ‘train’ and *standart* ‘standard,’ epenthesis occurs in such cases where Turkish puts a high vowel between consonant clusters according to vowel harmony. Therefore, they become [t̪ʰiɾɛn̪] and [s̪ɯt̪ʰɑn̪d̪ɑɾt̪ʰ] respectively. However, since C_0 denotes zero or more consonants, a mirror image rule will be applied here in order to capture the alternation without any violations. Accordingly, the vowel fronting rule in Turkish can be revised as follows:

Vowel fronting in Turkish (revised)

$$\begin{array}{c}\text{V}\\ [+\text{back}]\end{array} \rightarrow \underset{+}{\text{V}}\ \%\ \_\_\_ \left\{\begin{array}{c}\text{l}\\ \text{c}^{\text{h}}\\ \text{ɟ}\end{array}\right\} \text{C}_0\ \$$$

The vowel fronting rule in Turkish can be modified with the help of distinctive features. Unfortunately, /l/, /c^h/ and /ɟ/ do not form a single natural class. However, we can divide them into two natural classes, that is, /c^h/ and /ɟ/ are specified by [+coronal, -back] while /l/ is [+lateral, -dorsal]. Therefore, the vowel fronting rule can be written as follows:

Vowel fronting in Turkish (revised with features)

$$\begin{array}{c}\text{V}\\ [+\text{back}]\end{array} \rightarrow \underset{+}{\text{V}}\ \%\ \_\_\_ \left\{\begin{array}{c}\begin{bmatrix}+\text{lat}\\ -\text{dors}\end{bmatrix}\\ \begin{bmatrix}+\text{cor}\\ -\text{bk}\end{bmatrix}\end{array}\right\} \text{C}_0\ \$$$

Naturally, the vowel fronting rule in Turkish is also expected to apply to the high back unrounded vowel phoneme /ɯ/ although no occurrences of it have been found in such environments. For instance, /ɯ/ is never found in an environment where it follows /c^h/ at the beginning of a syllable. However, this does not invalidate the rule since no counterexample is available. The vowel fronting rule is also advantageous in that it predicts how /ɯ/ will behave in any possible occurrences of it in such environments.

It is important to note that the plus symbol seen below V in the vowel fronting rule denotes the advanced position of the vowel in question. This diacritic is shown in Figure 5 in Section 2.1.2.6. The advanced positions of these back vowels are also acoustically demonstrated in the vowel triangle of standard Turkish in Figure 46 in Section 4.1.1.2. Additionally, /ɑ/ undergoes the fronting rule and becomes [a], not [ɑ̟] since [a] is an existing IPA symbol and its placement on the chart is deemed suitable for this study. However, the other fronted back vowels are marked by a diacritic (i.e. [u̟] and [o̟]) as no other IPA symbol is appropriate for their positions on the chart.

4.1.2.2.2 Laxing In Turkish

[ɛ] appears to be an allophone of the mid unrounded phoneme /e/ in Turkish although the situation is much more complicated than it is for the back vowels. At first glance /e/ seems to become [ɛ] when it is followed by a nasal or a liquid in the same syllable. The nasals /m n̪/ and liquids /ɾ l ɫ̪/ form a natural class since they constitute all the [+sonorant, +consonantal] sounds of the language. As a result, a tentative rule might be formed:

Laxing in Turkish (preliminary)

$$\overset{\text{V}}{\begin{bmatrix} -\text{hi} \\ -\text{bk} \\ -\text{rd} \end{bmatrix}} \rightarrow [\text{-tns}] \;/\; \underline{\quad} \begin{bmatrix} +\text{son} \\ +\text{cons} \end{bmatrix} \$$$

However, /ɫ̪/ only follows a back vowel in the same syllable and /e/ is not a back vowel, thus /ɫ̪/ needs to be removed from the rule. In that case, we can benefit from the fact that the phonemes /m n̪ ɾ l/ are [+sonorant, +consonantal, -dorsal] while the velarized dental lateral /ɫ̪/ is [+sonorant, +consonantal, +dorsal] because of its velarization. Therefore, if we are to add [-dorsal] to [+sonorant, +consonantal] in the rule, we will be able to exclude /ɫ̪/. This alternation may be expressed as follows:

Laxing in Turkish (preliminary)

$$\overset{\text{V}}{\begin{bmatrix} -\text{hi} \\ -\text{bk} \\ -\text{rd} \end{bmatrix}} \rightarrow [\text{-tns}] \;/\; \underline{\quad} \begin{bmatrix} +\text{son} \\ +\text{cons} \\ -\text{dor} \end{bmatrix} \$$$

Although we are able to remove /ɫ̪/ from the rule with the addition of [-dorsal], the feature [+consonantal] can be deleted from the set [+sonorant, -dorsal] for the reason that it corresponds to the same set of sounds with or without the feature [+consonantal]. Therefore, a revised version of the rule may be expressed as follows:

Laxing in Turkish (preliminary)

$$\begin{bmatrix} \text{V} \\ -\text{hi} \\ -\text{bk} \\ -\text{rd} \end{bmatrix} \rightarrow [\text{-tns}] \ / \ \_\_\_ \begin{bmatrix} +\text{son} \\ -\text{dor} \end{bmatrix} \$$$

Table 25 shows the distribution of [ɛ] and [e]. As can be seen from Table 25, the environment of [e] is much more diverse than that of [ɛ]. Therefore, /e/ is realized as the phoneme.

Table 25. Distribution of [e] and [ɛ] in Turkish (needs revising).

	___m$	___n̪$	___ɾ$	___l$	elsewhere
[ɛ]	gözl*e*m	lütf*e*n	ask*e*r	k*e*l	
[e]					ac*e*l*e*, *e*t*e*k, p*e*ç*e*t*e*, k*e*l*e*b*e*k, g*e*v*e*z*e*

The pronunciation of *keten* ‘linen.NOM’ is [c^{h}et̪^{h}ɛn̪] while *keteni* ‘linen.ACC’ is transcribed as [c^{h}et̪^{h}en̪i]. This is due to the fact that /e/ is not in the same syllable with /n̪/ in the accusative case, thus failing to satisfy the environment ___n̪$. In addition, /e/ still becomes [ɛ] even if there are other consonants following the [+sonorant, -dorsal] sound in the same syllable. This can be seen in words such as *kırlent* ‘throw pillow’ and *özerk* ‘autonomous’ since /t̪^{h}/ and /c^{h}/ follow the [+sonorant, -dorsal] sounds respectively. Therefore, we may modify the rule by adding C_0 to represent zero or more consonants so that this situation is covered as well:

Laxing in Turkish (preliminary)

$$\begin{bmatrix} \text{V} \\ -\text{hi} \\ -\text{bk} \\ -\text{rd} \end{bmatrix} \rightarrow [\text{-tns}] \ / \ \_\_\_ \begin{bmatrix} +\text{son} \\ -\text{dor} \end{bmatrix} C_0 \ \$$$

There is also one more precaution that needs to be taken against words which has the letter <e> in their first syllable. Since *el* ‘hand,’ *en* ‘most,’ *em* ‘absorb.IMP,’ *elbise* ‘dress,’ *engel* ‘obstacle,’ *emsal* ‘precedent,’ *helva* ‘halva,’ *menzil* ‘range,’ *tembih* ‘warning,’ *belli* ‘apparent,’ *pencere* ‘window’ and *emlak* ‘real estate’ have [e] in their first syllable rather than [ɛ], we should exclude these environments in the rule where /e/ occurs in the first syllable of a word so that the rule does not predict the wrong surface representation. The important point to note is that among [+sonorant, -dorsal] sounds, only /ɾ/ triggers laxing word-initially as can be seen in words such as *er* ‘private.N,’ *erdem* ‘virtue’ and *erken* ‘early,’ all of which start with [ɛ]. Accordingly, the rule is modified with the addition of V_1 in order to prevent /e/ from occurring in the first syllable of a word. Once again, C_0 denotes zero or more [-syllabic] segments while V_1 represents at least one [+syllabic] segment. The first laxing rule in Turkish can be expressed as follows:

Laxing in Turkish – Rule A (revised)

$$\overset{\text{V}}{\begin{bmatrix}-\text{hi}\\-\text{bk}\\-\text{rd}\end{bmatrix}} \rightarrow [\text{-tns}] \ / \ V_1\, C_0 \ \_\_\_ \ \begin{bmatrix}+\text{son}\\-\text{dor}\end{bmatrix} C_0 \ \$$$

Even though Turkish Language Association (TDK) and Turkish Radio and Television Association (TRT) suggest [e] for the pronunciations of the letter <e> in *önem* ‘importance,’ *önemli* ‘important’ and *kalem* ‘pen(cil),’ Turkish speakers, following the rule instinctively, tend to pronounce the letter <e> as [ɛ]. TDK and TRT also use [e] for the second vowel in *cehennem* ‘hell’ in their audio dictionaries although we generally find Turkish speakers have a tendency to pronounce this vowel as [ɛ], thus conforming to *Rule A* again. *Rule A* can apply readily in novel utterances in Turkish. For example, if you have written a non-existent word such as, say, ‘*malereterlem’* on a piece of paper and asked native Turkish speakers to pronounce it, they will articulate the word as [mɑleɾet̪ʰɛɾlɛm], which is the completely expected result according to the rule. Although *Rule A* is not free of problems, seeming exceptions to the rule, such as *kel* ‘bald,’ *sel* ‘flood,’ *ben* ‘I,’ *sen* ‘you,’ *fen* ‘science,’ *şen* ‘happy’ all of which are pronounced with [ɛ] rather than [e], will be handled by *Rule B.*

Table 26 below is an attempt to simplify the eligibility of *Rule A* with the help of some words. If there is more than one reason why the rule does not apply to a specific environment, then only one is expressed.

Table 26. Applicability of Rule A.

word 'gloss'	environment of /e/	applicability of Rule A	if not applicable, why not
*e*mir 'command'	# ____ $ m	X	first syllable
bird*e*n 'suddenly'	d̪ ____ n̪ $	✓	—
küp*e* 'earring'	p^h ____ $	X	no [+son, -dor] segment
çeng*e*l 'hook'	ɟ ____ l $	✓	—
ç*e*ngel 'hook'	# ____ n̪ $	X	first syllable
sist*e*m 'system'	t̪^{h} ____ m $	✓	—
t*e*myiz 'appeal'	t̪^{h} ____ m $	X	first syllable
zaf*e*r 'victory'	f ____ ɾ $	✓	—
nükl*e*er 'nuclear'	l ____ $ e	X	no [+son, -dor] segment
nükle*e*r 'nuclear'	e ____ ɾ $	✓	—
c*e*nnet 'heaven'	dʒ ____ n̪ $	X	first syllable
ef*e*ndi 'master'	f ____ n̪ $	✓	—
cenn*e*t 'heaven'	n̪ ____ t̪^{h} $	X	no [+son, -dor] segment
No*e*l 'Christmas'	o ____ l $	✓	—
*e*fendi 'master'	# ____ $ f	X	first syllable

Rule A by its nature only deals with polysyllabic words, thus cannot explain the occurrences of [ɛ] in many monosyllabic words. The second laxing rule in Turkish, *Rule B*, solves this problem. In order for /e/ to become [ɛ] in monosyllabic words, the environment needs to be #C____ {n̪, l, ɾ}#. Despite being a [+sonorant, -dorsal] segment, /m/ does not trigger laxing in such monosyllabic words. Some monosyllabic words which end with a

[+sonorant, -dorsal] sound, satisfy the #C____ C# environment and have <e> as their nucleus are presented in Table 27.

Table 27. Examples for words satisfying the #C____ [+sonorant, -dorsal]# environment.

#C____ n̪#	/e/	#C____ l#	/e/	#C____ ɾ#	/e/	#C____ m#	/e/
ben ‘I’	[ɛ]	*bel* ‘waist’	[ɛ]	*fer* ‘luster’	[ɛ]	*cem* ‘gathering’	[e]
fen ‘science’	[ɛ]	*gel* ‘come.IMP’	[ɛ]	*her* ‘every’	[ɛ]	*dem* ‘brew.N (tea)’	[e]
gen ‘gene’	[ɛ]	*jel* ‘gel’	[ɛ]	*ker* ‘power’	[ɛ]	*gem* ‘bridoon’	[e]
sen ‘you’	[ɛ]	*kel* ‘bald’	[ɛ]	*ser* ‘head’	[ɛ]	*hem* ‘also’	[e]
şen ‘happy’	[ɛ]	*sel* ‘flood’	[ɛ]	*şer* ‘evil.N’	[ɛ]	*kem* ‘evil.ADJ’	[ɛ]
ten ‘skin’	[ɛ]	*tel* ‘wire’	[ɛ]	*ter* ‘sweat’	[ɛ]	*nem* ‘moisture’	[e]
zen ‘woman’	[ɛ]	*yel* ‘breeze’	[ɛ]	*yer* ‘place’	[ɛ]	*yem* ‘bait.N’	[e]

Table 27 reveals that the phoneme /e/ always becomes [ɛ] when the environment is #C____{n̪, l, ɾ}#. The exclusion of /m/ from the environment seems to be justified; however, there is one exception, *kem* ‘evil.ADJ,’ in which /e/ surfaces as [ɛ] although this is not predicted by *Rule B* below.

Laxing in Turkish – Rule B (preliminary)

$$\overset{\text{V}}{\begin{bmatrix} -\text{hi} \\ -\text{bk} \\ -\text{rd} \end{bmatrix}} \rightarrow [\text{-tns}] \,/\, \#\,\text{C}\,\_\_\_ \begin{bmatrix} +\text{son} \\ -\text{dor} \\ -\text{lab} \end{bmatrix} \#$$

/m/ is excluded from *Rule B* with the addition of the feature [-labial]. The only segment that is [+labial] among non-dorsal sonorants is /m/. The remaining [+sonorant, -dorsal] segments are all [-labial]. Therefore, we can exclude /m/ from this list with the help of the [+/-labial] feature. However, *Rule B* cannot predict the surface representation of /e/ as [ɛ] in words such as *kent* ‘city,’ *felç* ‘stroke’ and *sert* ‘hard’ all of which has the environment #C____{n̪, l, ɾ}C_0#. Therefore, the addition of such an environment will be beneficial to the productivity of *Rule B.*

Laxing in Turkish – Rule B (revised)

$$\begin{bmatrix} \text{V} \\ -\text{hi} \\ -\text{bk} \\ -\text{rd} \end{bmatrix} \rightarrow [\text{-tns}] \ / \ \# \ \text{C} \ \_\_\_ \begin{bmatrix} +\text{son} \\ -\text{dor} \\ -\text{lab} \end{bmatrix} \text{C}_0 \ \#$$

The third laxing rule in Turkish solely concerns the environment of /ɾ/. *Rule C* is a great instance of a fully productive rule which is applied by speakers instinctively and automatically whenever the conditions are met. *Rule C* is as follows:

Laxing in Turkish – Rule C

$$\begin{bmatrix} \text{V} \\ -\text{hi} \\ -\text{bk} \\ -\text{rd} \end{bmatrix} \rightarrow [\text{-tns}] \ / \ \# \ \text{C}_0 \ \_\_\_ \ [+\text{tap}] \ \text{C}_0 \ \$$$

According to *Rule C*, if /e/ happens to occur word-initially or in the first syllable of a word, it becomes [ɛ] when followed by /ɾ/ in the same syllable. Also, it should be noted that this word-initial and first-syllable environment is only included in *Rule C* in contrast to *Rule A*, *Rule B* and *Rule D*. The applicability of *Rule C* is shown in Table 2. Again, if the rule does not apply due to two or more reasons, then only one of them is displayed.

Table 28. Applicability of Rule C.

word ‘gloss’	**environment of /e/**	**applicability of Rule C**	**if not applicable, why not**
der*e* ‘stream’	ɾ ____ $	X	no [+tap] segment
*e*rk ‘puissance’	# ____ ɾ C $	✓	—
c*e*bren ‘by force’	dʒ ____ b	X	no [+tap] segment
*e*rgen ‘adolescent’	# ____ ɾ $	✓	—
ber*e* ‘beret’	ɾ ____ #	X	no [+tap] segment
*e*rbap ‘expert’	# ____ ɾ $	✓	—
g*e*ri ‘back’	ɟ ____ $ ɾ	X	syllabicity
*e*rmek ‘reach’	# ____ ɾ $	✓	—
s*e*ri ‘serial’	s̪ ____ $ ɾ	X	syllabicity
*e*rzak ‘provisions’	# ____ ɾ $	✓	—
çer*e*z ‘snack’	ɾ ____ z̪	X	no [+tap] segment
*e*r ‘private.N’	# ____ ɾ $	✓	—
*e*roin ‘heroin’	# ____ $ ɾ	X	syllabicity
*e*rden ‘virgin’	# ____ ɾ $	✓	—

The three laxing rules mentioned so far in this study, namely *Rule A*, *Rule B* and *Rule C*, have been connected with non-dorsal sonorant sounds. However, there exists an unusual and unnatural environment which does not include any non-dorsal sonorant after /e/ in the same syllable, but still triggers laxing in Turkish. Specifically, if /e/ is preceded by /m/ and followed by /z̪/ in the same syllable except word-initially, [ɛ] surfaces. To give an example, this situation can be observed in verbal adjectives with the *–mAz* suffix, which is the negative aorist participle in Turkish (Özünlü, 1984). In addition, some adjectives have conventionally changed into nouns such as *etyemez* ‘vegetarian’ and *hüryemez* ‘an apple cultivar’ while others still retain their lexical categories as adjectives, e.g. *görünmez* ‘invisible’ and *kurşungeçirmez* ‘bulletproof’. Furthermore, apart from words which have the suffix *–mAz*, words containing *mez* in a single syllable (e.g. *pekmez* 'grape molasses') also have [ɛ] in the surface representation. Accordingly, the last laxing rule in Turkish is provided below:

Laxing in Turkish – Rule D

$$\begin{bmatrix} \mathrm{V} \\ -\mathrm{hi} \\ -\mathrm{bk} \\ -\mathrm{rd} \end{bmatrix} \rightarrow [\text{-tns}] \;/\; V_1\, C_0\, \$ \begin{bmatrix} +\mathrm{nas} \\ +\mathrm{lab} \end{bmatrix} \_\_ \begin{bmatrix} +\mathrm{voi} \\ +\mathrm{ant} \\ +\mathrm{stri} \end{bmatrix} \$$$

In *Rule D*, /m/ is the only member in the [+nasal, +labial] set. Similarly, it is observed that [+voice, +anterior, +strident] only corresponds to /z̪/. As in *Rule A*, V_1 and C_0 are added to *Rule D* in an attempt to exclude the word-initial position. The applicability of *Rule D* is shown in Table 29. If the rule does not apply because of more than just one reason, only one cause is demonstrated.

In Table 29, /e/ surfaces as [e] in the environments where *Rule D* does not apply. However, when the conditions are met, /e/ becomes [ɛ]. The word *çömez* 'rookie' which ends with [e] seems to be an exception to *Rule D*. Additionally, when *çömez* takes derivational or inflectional morphemes, *Rule D* still cannot apply to these forms such as *çömezden* 'rookine.ABL' and *çömezlik* 'the state of being a rookie'. However, according to Nişanyan (2017), *çömez* originated from *çömelmek* 'crouch' whose root seems to be *çök-* or *çöŋ-* in Old Turkic. Therefore, if we cling on to the assumption that *çöŋ-*, for example, took the suffix +Az at first for what became *çömez* afterwards, then this may enable us to explain why /e/ does not surface as [ɛ]. Nevertheless, it is important to note that this approach should be viewed with suspicion.

Table 29. Applicability of Rule D.

word 'gloss'	**environment of /e/**	**applicability of Rule D**	**if not applicable, why not**
m*e*zar 'tomb'	$ m ____ $ z̪	X	syllabicity
görünm*e*z 'invisible'	$ m ____ z̪ $	✓	—
m*e*zgit 'haddock'	$ m ____ z̪ $	X	first syllable
etyem*e*z 'vegetarian'	$ m ____ z̪ $	✓	—
m*e*zhep 'creed'	$ m ____ z̪ $	X	first syllable
sugötürm*e*z 'incontestable'	$ m ____ z̪ $	✓	—
m*e*ze 'meze'	$ m ____ $ z̪	X	syllabicity
varyem*e*z 'penny-pinching'	$ m ____ z̪ $	✓	—
m*e*zosfer 'mesosphere'	$ m ____ $ z̪	X	syllabicity
pekm*e*z 'grape molasses'	$ m ____ z̪ $	✓	—
m*e*zuniyet 'graduation'	$ m ____ $ z̪	X	syllabicity
erim*e*z 'insoluble'	$ m ____ z̪ $	✓	—
m*e*zra 'arable field'	$ m ____ z̪ $	X	first syllable
iyilikbilm*e*z 'ungrateful'	$ m ____ z̪ $	✓	—

Before examining how the laxing rules in Turkish give the correct surface forms, it would probably be very beneficial to recapitulate all the laxing rules. *Rule A*, *Rule B*, *Rule C* and *Rule D* are provided as follows:

Laxing in Turkish – Rule A

$$\begin{matrix}\text{V}\\ \begin{bmatrix}-\text{hi}\\ -\text{bk}\\ -\text{rd}\end{bmatrix}\end{matrix} \rightarrow [\text{-tns}]\ /\ V_1\ C_0 \_\_\_ \begin{bmatrix}+\text{son}\\ -\text{dor}\end{bmatrix} C_0\ \$$$

Laxing in Turkish – Rule B

$$\begin{matrix}\text{V}\\ \begin{bmatrix}-\text{hi}\\ -\text{bk}\\ -\text{rd}\end{bmatrix}\end{matrix} \rightarrow [\text{-tns}]\ /\ \#\ C \_\_\_ \begin{bmatrix}+\text{son}\\ -\text{dor}\\ -\text{lab}\end{bmatrix} C_0\ \#$$

Laxing in Turkish – Rule C

$$\begin{matrix}\text{V}\\ \begin{bmatrix}-\text{hi}\\ -\text{bk}\\ -\text{rd}\end{bmatrix}\end{matrix} \rightarrow [\text{-tns}]\ /\ \#\ C_0 \_\_\_ [+\text{tap}]\ C_0\ \$$$

Laxing in Turkish – Rule D

$$\begin{matrix}\text{V}\\ \begin{bmatrix}-\text{hi}\\ -\text{bk}\\ -\text{rd}\end{bmatrix}\end{matrix} \rightarrow [\text{-tns}]\ /\ V_1\ C_0\ \$ \begin{bmatrix}+\text{nas}\\ +\text{lab}\end{bmatrix} \_\_\_ \begin{bmatrix}+\text{voi}\\ +\text{ant}\\ +\text{stri}\end{bmatrix} \$$$

A number of words which contain /e/ in their underlying representations and all the laxing rules are provided in Table 30-38 to show how and when /e/ in the underlying representation (UR) surfaces as [ɛ] or [e] in the surface representation (SR). Syllable boundaries within a word are shown with the period (.) at the top of the tables since they are of great importance to the applicability of the laxing rules. In addition to the vowel alternation, one can see that a number of consonants are different in the surface representation as well. This is due to the fact that they also undergo certain phonological processes which are beyond the scope of this study.

Table 30. Laxing rules applying to the phrase ‘ergenleşmek’.

phrase ‘gloss’	er.gen.leş.mek ‘reach maturity’
UR	/eɾɟen̪leʃmecʰ/
Rule A = $e \rightarrow \varepsilon / V_1\ C_0 \_\_\_\_ \{m\ \text{n̪}\ l\ \text{ɾ}\}\ C_0\ \$$	ε
Rule B = $e \rightarrow \varepsilon / \#\ C \_\_\_\_ \{\text{n̪}\ l\ \text{ɾ}\}\ C_0\ \#$	
Rule C = $e \rightarrow \varepsilon / \#\ C_0 \_\_\_\_ \text{ɾ}\ C_0\ \$$	ε
Rule D = $e \rightarrow \varepsilon / V_1\ C_0\ \$\ m \_\_\_\_ \text{z̪}\ \$$	
SR	[ɛɾɟɛn̪leʃmecʰ]

Table 31. Laxing rules applying to the phrase ‘ertelenmez’.

phrase ‘gloss’	er.te.len.mez ‘it will not get postponed’
UR	/eɾt̪ʰelen̪mez̪/
Rule A = $e \rightarrow \varepsilon / V_1\ C_0 \_\_\_\_ \{m\ \text{n̪}\ l\ \text{ɾ}\}\ C_0\ \$$	ε
Rule B = $e \rightarrow \varepsilon / \#\ C \_\_\_\_ \{\text{n̪}\ l\ \text{ɾ}\}\ C_0\ \#$	
Rule C = $e \rightarrow \varepsilon / \#\ C_0 \_\_\_\_ \text{ɾ}\ C_0\ \$$	ε
Rule D = $e \rightarrow \varepsilon / V_1\ C_0\ \$\ m \_\_\_\_ \text{z̪}\ \$$	ε
SR	[ɛɾt̪ʰelɛn̪mɛz̪/

Table 32. Laxing rules applying to the phrase ‘kertenkelelerden’.

phrase ‘gloss’	ker.ten.ke.le.ler.den ‘lizards.ABL’
UR	/cʰeɾt̪ʰen̪cʰeleleɾd̪en̪/
Rule A = $e \rightarrow \varepsilon / V_1\ C_0 \_\_\_\_ \{m\ \text{n̪}\ l\ \text{ɾ}\}\ C_0\ \$$	ε ε ε
Rule B = $e \rightarrow \varepsilon / \#\ C \_\_\_\_ \{\text{n̪}\ l\ \text{ɾ}\}\ C_0\ \#$	
Rule C = $e \rightarrow \varepsilon / \#\ C_0 \_\_\_\_ \text{ɾ}\ C_0\ \$$	ε
Rule D = $e \rightarrow \varepsilon / V_1\ C_0\ \$\ m \_\_\_\_ \text{z̪}\ \$$	
SR	[cʰɛɾt̪ʰɛn̪cʰelelɛɾd̪ɛn̪]

Table 33. Laxing rules applying to the phrase ‘cehennem’.

phrase ‘gloss’	ce.hen.nem ‘hell’
UR	/dʒehen̪n̪em/
Rule A = e → ε / V_1 C_0 ____ {m n̪ l ɾ} C_0 $	ε ε
Rule B = e → ε / # C ____ {n̪ l ɾ} C_0 #	
Rule C = e → ε / # C_0 ____ ɾ C_0 $	
Rule D = e → ε / V_1 C_0 $ m ____ z̪ $	
SR	[dʒehɛn̪n̪ɛm]

Table 34. Laxing rules applying to the phrase ‘şen telesekreterler’.

phrase ‘gloss’	şen te.le.sek.re.ter.ler ‘happy answering machines’
UR	/ʃen̪ t̪ʰeles̪ecʰɾet̪ʰeɾleɾ/
Rule A = e → ε / V_1 C_0 ____ {m n̪ l ɾ} C_0 $	ε ε
Rule B = e → ε / # C ____ {n̪ l ɾ} C_0 #	ε
Rule C = e → ε / # C_0 ____ ɾ C_0 $	
Rule D = e → ε / V_1 C_0 $ m ____ z̪ $	
SR	[ʃɛn̪ t̪ʰeles̪ecɾet̪ʰɛɾlɛɾ̝̊]

Table 35. Laxing rules applying to the phrase ‘eğer gelenekselleşmezse’.

phrase ‘gloss’	e.ğer ge.le.nek.sel.leş.mez.se ‘if it does not become a tradition’
UR	/eɣeɾ ɟelen̪ecʰs̪elleʃmez̪s̪e/
Rule A = e → ε / V_1 C_0 ____ {m n̪ l ɾ} C_0 $	ε ε
Rule B = e → ε / # C ____ {n̪ l ɾ} C_0 #	
Rule C = e → ε / # C_0 ____ ɾ C_0 $	
Rule D = e → ε / V_1 C_0 $ m ____ z̪ $	ε
SR	[ejɛɾ ɟelen̪ecs̪ɛlleʃmɛz̪s̪e]

Table 36. Laxing rules applying to the phrase ‘beynelmilel medeniyetler sel sevmez’.

phrase ‘gloss’	bey.nel.mi.lel me.de.ni.yet.le.r sel sev.mez ‘international civilizations don’t like floods’
UR	/bejn̪elmilel med̪en̪ijet̪^{h}leɾ s̪el s̪evmez̪/
Rule A = e → ε / V_1 C_0 ____ {m n̪ l ɾ} C_0 $	ε ε ε
Rule B = e → ε / # C ____ {n̪ l ɾ} C_0 #	ε
Rule C = e → ε / # C_0 ____ ɾ C_0 $	
Rule D = e → ε / V_1 C_0 $ m ____ z̪ $	ε
SR	[bejn̪ɛlmilɛl med̪en̪ijet̪lɛɾ̥ s̪ɛl s̪evmɛz̪]

Table 37. Laxing rules applying to the phrase ‘her erkek genelgeçer gerçeği göremez’.

phrase ‘gloss’	her er.kek ge.nel.ge.çer ger.çe.ği gö.re.mez ‘not every man can see the universal fact’
UR	/heɾ eɾc^{h}ec^{h} ɟen̪elɟetʃ^{h}eɾ ɟeɾtʃ^{h}eɣi ɟøɾemez̪/
Rule A = e → ε / V_1 C_0 ____ {m n̪ l ɾ} C_0 $	ε ε
Rule B = e → ε / # C ____ {n̪ l ɾ} C_0 #	ε
Rule C = e → ε / # C_0 ____ ɾ C_0 $	ε ε
Rule D = e → ε / V_1 C_0 $ m ____ z̪ $	ε
SR	[hɛɾ ɛɾc^{h}ec ɟen̪ɛlɟetʃ^{h}ɛɾ ɟɛɾtʃ^{h}eɣi ɟøɾemɛz̪]

Table 38. Laxing rules applying to the phrase ‘kelepçelere ellemeden gel sen’.

phrase ‘gloss’	ke.lep.çe.le.re el.le.me.den gel sen ‘come here without touching the handcuffs’
UR	/c^{h}elep^{h}tʃ^{h}eleɾe ellemed̪en̪ ɟel s̪en̪/
Rule A = e → ε / V_1 C_0 ____ {m n̪ l ɾ} C_0 $	ε
Rule B = e → ε / # C ____ {n̪ l ɾ} C_0 #	ε ε
Rule C = e → ε / # C_0 ____ ɾ C_0 $	
Rule D = e → ε / V_1 C_0 $ m ____ z̪ $	
SR	[c^{h}eleptʃ^{h}eleɾe ellemed̪ɛn̪ ɟɛl s̪ɛn̪]

CHAPTER 5

CONCLUSION

The vowel triangle of Turkish in Figure 46 presents a phonetic frame of reference. It does not reify any particular phonological theory. The fact that the vowel nodes on the periphery are denoted by black circles mainly serves a practical purpose. It also aims to conserve the cardinal vowels principle of Jones (1966), which is helpful in the classification and notation of the sounds of the languages in the world. In addition, it can be observed that the vowel triangle embodies the classic parameters (i.e. closeness, backness and rounding) which are utilized in phonology. Nonetheless, the vowel triangle refrains from unjustified predispositions which conceal significant generalizations. Specifically, it brings to light the triangular shape of the vowel space and the discrete characteristic of primary peripheral qualities. These conditions are masked by the four-cornered quadrilateral tongue chart of the IPA. The vowels that are at the corners in the triangular vowel chart in Figure 46 are [i], [a] and [u]. These sounds are the corner vowels in a large number of languages and equate to the primes |I|, |A| and |U| in Element Theory (Kaye, Lowenstamm, & Vergnaud, 1985, 1990; Harris, 1994; Harris & Lindsey, 1995).

Lindsey (2017) maintains that there is an intentional ambiguity in the position of [a] on the vowel chart as drawn in Figure 27 in which [a] is allocated as a front vowel but also positioned centrally. The main idea behind the intentional front/back ambiguity of [a] is that it can occur as a back vowel in a number of languages. As a matter of fact, [a] is a back vowel and an allophone of [ɑ] in Turkish.

In addition to the vowel triangle of Turkish, the study deals with two phonological processes regarding the vowels in the language. Firstly, the vowel fronting rule is provided in Section 4.1.2.2.1. With this rule, we can understand how /o/ becomes [o̟], /u/ becomes [u̟] and /ɑ/ becomes [a]. Furthermore, four rules are presented in order to account for the laxing in Turkish as the situation is much more complicated than that of the vowel fronting process.

The acoustic analysis in the study was done within the context of RQ1 that is given as follows:

> RQ1. In line with the triangular vowel chart proposed by Lindsey (2017), how can the phonetic inventory of Turkish vowels be represented in a way that is closer to phonetic reality of the vowel space?

The starting point for this study is the idea that the vowel space is distorted in many ways by the IPA vowel quadrilateral. In addition, the criticism of Well (2009) is that “the middle of the IPA chart represents an excessive enthusiasm for a non-Jonesian extension of the Cardinal Vowel scheme” and that a number of symbols on the IPA vowel chart are simply the outcome of “a desire to label every intersection of lines on the chart, rounded and unrounded.”

In this study, following the acoustically realistic vowel triangle of Lindsey (2017), a triangular vowel chart of standard Turkish is provided. In this chart, the low central unrounded vowel position is filled by [a]. Also, the lip postures are specified on the vowel triangle. The vowels on the periphery and their horizontal neighbors vary in rounding in that those to the left are unrounded although many positions on the quadrilateral can denote two separate vowels with two separate lip postures. The triangular vowel chart can be considered as conservative to the extent that it specifies the classical descriptions of ‘backness,’ ‘closeness’ and ‘rounding’ which are generally used by phonologists.

The vowel triangle of Turkish is comprised of 12 vowels, namely [a ɑ e ɛ ɯ i o o̦ ø u u̦ y]. These vowels occurred in a total of 51 words in the study. The recordings of the words with a short definition for each were collected by 10 standard Turkish speakers who identified themselves as five males and five females. The segmentation of the vowels in question was carried out based on a number of acoustic cues mentioned in Section 3.2.3. Out of 960 vowel tokens from 10 speakers, 29 of them were excluded from the study due to the difficulty in the segmentation of those sounds. F_1 and F_2 values for each vowel for all the speakers were obtained at the midpoint of their duration since coarticulation effects will be less powerful. The mean formant frequencies were calculated for each speaker and for each gender thereafter. The Lobanov (1971) method of normalization, which uses z-score, was used on the vowels. In this method, formant values of each speaker are put on a scale of standard deviations. The vowel triangle of standard Turkish, drawn according to the means of the normalized vowel formants for all the speakers, is shown in Figure 46 with additional connecting lines as a visual assistance. Moreover, equal spacing is satisfied as the symbols of the vowels are adjusted. Ultimately, the triangular vowel chart of Turkish is constructed based on acoustic fact. This chart, which is the first in the field, is aimed to serve as a reference vowel chart for further studies on Turkish vowels.

The phonological analysis in the study was done within the scope of RQ2 which is given as follows:

> RQ2. How can the Turkish vowel phonemes and allophones be expressed with phonological processes and rules?

In Section 4.1.2.2, the vowel allophones in Turkish are examined and conditioned by several phonological rules. The vowel fronting rule takes place if a back vowel phoneme is immediately preceded or followed by /l/, /c^{h}/ or /ɟ/ in the same syllable. Only /ɯ/ does not have a fronted counterpart whereas /u o ɑ/ become [u̟ o̟ a] respectively if the conditions are met. In fact, /ɯ/ is never immediately preceded or followed by /l/, /c^{h}/ or /ɟ/ in the same syllable in standard Turkish. The plus signs below the vowels show that these fronted or advanced sounds are articulated farther to the front in the mouth. The vowel fronting rule in standard Turkish is as follows:

Vowel fronting in Turkish

$$\overset{\text{V}}{\begin{bmatrix} -\text{hi} \\ -\text{bk} \\ -\text{rd} \end{bmatrix}} \rightarrow \underset{+}{\text{V}} \ \% \ \_\_\_ \begin{Bmatrix} \text{l} \\ \text{c}^{\text{h}} \\ \text{ɟ} \end{Bmatrix} \text{C}_0 \ \$$$

In addition to the vowel fronting, we can also observe the laxing of /e/ in some environments. At first sight, /e/ seems to become [ɛ] when it is followed by a sonorant (i.e. /m n̪ ɾ l/) in the same syllable as in *gözlem* ‘observation,’ *lütfen* ‘please (exclam.),’ *asker* ‘soldier’ and *kel* ‘bald’ (Erguvanlı-Taylan, 2015). Nevertheless, words such as *el* ‘hand,’ *en* 'most,' *em* 'absorb.IMP,' *elbise* 'dress,' *engel* 'obstacle,' *emsal* 'precedent,' *helva* 'halva,' *menzil* 'range,' *tembih* 'warning,' *belli* 'apparent,' *pencere* 'window' and *emlak* 'real estate' have [e] in their first syllable as opposed to [ɛ] despite preceding a sonorant. Therefore, the laxing rule in Turkish needed to be revised. The aforementioned examples are accounted for by *Rule A* according to which the first syllable is excluded. [ɛ] is also observed in quite a few monosyllabic words. This is not explained by *Rule A*, thus a new rule is proposed about the occurrences of [ɛ] in monosyllabic environments. *Rule B* allows /e/ to become [ɛ] in monosyllabic words unless it is followed by /m/. To give an example, *ten* 'skin,' *tel* 'wire' and *ter* 'sweat' are pronounced with [ɛ] whereas *nem* 'moisture,' *dem* 'brew.N (tea)' and *yem* 'bait.N' are articulated with [e] according to *Rule B*. In addition, it has been mentioned that /ɾ/ has a noteworthy place among the non-dorsal sonorants (i.e. /m n̪ l ɾ/) in Turkish. This characteristic is elucidated by *Rule C* in accordance with which /e/ becomes [ɛ] if it occurs word-initially or in the first syllable of a word when followed by /ɾ/ in the same syllable. The occurrences of [ɛ] in the first syllables of the words *erk* 'puissance,' *ergen* 'adolescent,' *erzak* 'provisions' and *er* 'private.N' can be accounted for with the help of *Rule C*. Lastly, /e/ becomes [ɛ] when it follows /m/ and precedes /z̪/ in the same syllable except word-initially. The laxing rules in Turkish are as follows:

Rule A = e → ɛ / V_1 C_0 ____ {m n̪ l ɾ} C_0 $

Rule B = e → ɛ / # C ____ {n̪ l ɾ} C_0 #

Rule C = e → ɛ / # C_0 ____ ɾ C_0 $

Rule D = e → ɛ / V_1 C_0 $ m ____ z̪ $

5.1 LIMITATIONS OF THE STUDY

One of the major limitations of the study was the difficulty of reaching voluntary participants for the study. It is generally considered that finding participants is already a challenge. It was virtually impossible to record the voices of people and collect data during the COVID-19 pandemic in the world. In the end, 10 benevolent speakers, five males and five females, of standard Turkish volunteered for the experiment. A similar study can be carried out in the future with more participants.

Also, the lack of resources on the subject of phonological processes in Turkish obstructed the literature review and discussion of the findings to a certain extent. Ergo the laxing rules in the study must be interpreted as ambitious attempts to account for the vowel laxing seen in standard Turkish.

5.2 SUGGESTIONS FOR FURTHER STUDIES AND IMPLICATIONS

Vowel charts which are based on acoustic facts can be drawn for other languages as in this study. The functionality of such reference charts can be revealed by means of the advancement in speech technology. Unbiased standardized reference charts could be provided with the help of natural-sounding syntheses created for the vowels. Therefore, these standardized sounds could be utilized in phonological analysis and teaching.

It is known that Turkish has a large number of dialects (Karahan, 1996). A similar study could be carried out on a dialect of Turkish as vowels may differ in dialects. In this way, possible differences between the standard dialect and others could unfold. Especially, phonological alternations in other dialects can be useful in terms of understanding the nature of the history of the Turkish vowels in general.

Another point is that consonants in Turkish can be examined thoroughly in further studies since the full inventory of Turkish consonants is not sufficiently researched. Although the topic of consonants is not the primary focus of the study, a tentative table for consonants is provided in Table 17 in Section 2.9 because they are used in the transcriptions of words along with vowels. Understanding the place or manner of Turkish consonants helps grasp the phonological processes behind the alternations. Therefore, it is important that Turkish consonants be given emphasis by future experimental studies which could exhibit the features of them and present a more definite consonant inventory than the one used in this study.

Lastly, all the laxing rules except for *Rule D* contain non-dorsal sonorants following /e/ in the same syllable. The environment of *Rule D* in laxing of the vowel /e/ seems so unnatural that it begs the question as to why it happens. There is definitely more to the laxing of /e/ in Turkish than meets the eye. Etymological analysis may shed light on this issue.

REFERENCES

Adank, P., Smits, R., & van Hout, R. (2004). A comparison of vowel normalization procedures for language variation research. *The Journal of the Acoustical Society of America, 116*(5), 3099-3107.

Aksan, D., Atabay, N., & Özel, S. (1978). *Türkiye Türkçesi gelişmeli sesbilimi.* Ankara: TDK Yayınları.

Arısoy, E., Arslan, L., Nakipoğlu-Demiralp, M., Ekenel, H. K., Kelepir, M., Meral, H. M., . . . Yolcu, B. C. (2008, January 29). *Turkish phonetics.* Retrieved from https://slideplayer.biz.tr/slide/3200593/

Ashby, M., & Maidment, J. (2005). *Introducing phonetic science.* Cambridge: Cambridge University Press.

Aur alfəbits. (1888). *Le Maître Phonétique, 3*(5), 34-35.

Aydın, Ö., & Uzun, İ. P. (2020). Ünlü formant normalizasyonu: R programlama dilinde bir uygulama. In İ. P. Uzun (Ed.), *Kuramsal ve uygulamalı sesbilim* (pp. 297-322). Ankara: Seçkin Yayıncılık.

Bamgboṣe, A. (1969). Yoruba. In E. Dunstan (Ed.), *Twelve Nigerian languages. A handbook on their sound systems for teachers of English* (p. 166). New York: Africana Publishing Corp.

Banguoğlu, T. (2007). *Türkçenin grameri.* Ankara: Türk Dil Kurumu Yayınları.

Bell, A. M. (1867). *Visible speech: The science of universal alphabetics.* London: Simpkin, Marshall & Co.

Bloch, B. (1953). Contrast. *Language, 29*(1), 59-61.

Boersma, P., & Weenink, D. (2020). Praat: Doing phonetics by computer (Version 6.1.14) [Computer program]. Retrieved from http://www.praat.org/

Brosnahan, L. F., & Malmberg, B. (1970). *Introduction to phonetics.* S.I.: Heffer and Sons.

Campbell, G. (1995). *Concise compendium of the world's languages.* London: Routledge.

Catford, J. C. (1983). Pharyngeal and laryngeal sounds in Caucasian languages. *Vocal Fold Physiology: Contemporary Research and Clinical Issues*, 344-350.

Chiba, T., & Kajiyama, M. (1941). *The vowel: Its nature and structure*. Tokyo: Kaiseikan.

Chomsky, N., & Halle, M. (1968). *The sound pattern of English.* New York: Harper & Row.

Clark, J., & Yallop, C. (1990). *An introduction to phonetics and phonology.* Oxford: Blackwell.

Coşkun, V. (1999). Türkiye Türkçesinde ünlüler ve ünsüzler. *Türk Dili Araştırmaları Yıllığı Belleten*, 41-50.

Coşkun, V. (2001). Standart Türkçedeki ünlüler ve ünsüzler. *Muğla Üniversitesi Sosyal Bilimler Enstitüsü Dergisi*, 67-81.

Coşkun, V. (2008). *Türkçenin ses bilgisi.* İstanbul: IQ Kültür Sanat Yayıncılık.

Davenport, M., & Hannahs, S. J. (2005). *Introducing phonetics and phonology.* London: Hodder Education.

Davies, I. R., MacDermid, C., Corbett, G. G., McGurk, H., Jerrett, D., Jerrett, T., & Sowden, P. (1992). Color terms in Setswana: A linguistic and perceptual approach. *Linguistics*, *30*(6), 1065–1103.

Dell, F., & Elmedlaoui, M. (1985). Syllabic consonants and syllabification in Imdlawn Tashlhiyt Berber. *Journal of African Languages and Linguistics, 7*, 105-130.

Dell, F., & Elmedlaoui, M. (1988). Syllabic consonants in Berber: Some new evidence. *Journal of African Languages and Linguistics, 10*, 1-17.

Dell, F., & Elmedlaoui, M. (1992). Quantitative transfer in the nonconcatenative morphology of Imdlawn Tashlhiyt Berber. *Journal of Afroasiatic Languages, 3*, 89-125.

Demircan, Ö. (2009). *Türkçenin ses dizimi.* İstanbul: Der Yayınları.

Erem, T., & Sevin, N. (1947). *Fonetik işaretleriyle konuşma dilimiz.* İstanbul: Milli Eğitim Basımevi.

Ergenç, İ. (1989). *Türkiye Türkçesinin görevsel sesbilimi: Sesbirimlere genel bir bakış*. Ankara.

Ergenç, İ. (2002). *Konuşma dili ve Türkçenin söyleyiş sözlüğü.* İstanbul: Multilingual Yabancı Dil Yayınları.

Ergenç, İ., & Uzun, İ. P. (2017). *Türkçenin ses dizgesi.* Ankara: Seçkin Yayıncılık.

Erguvanlı-Taylan, E. (2015). *The phonology and morphology of Turkish.* İstanbul: Boğaziçi University Press.

Evans, N. (1995). Current issues in the phonology of Australian languages. In J. A. Goldsmith (Ed.), *The handbook of phonological theory* (pp. 723–761). Cambridge: Blackwell.

Fant, G. (1960). *The acoustic theory of speech production.* The Hague: Mouton.

Fant, G. (1986). Glottal flow: models and interaction. *Journal of Phonetics*, *14*, 393-9.

Fry, D. B. (2012). *The physics of speech.* Cambridge: Cambridge University Press.

Gemalmaz, E. (1980). Türkçenin fonemler düzeni ve bu fonemlerin işleyişi. *Fen-Edebiyat Fakültesi Edebiyat Bilimleri Araştırma Dergisi*, 173-196.

Gemalmaz, E. (1999). Türkiye Türkçesinde ses olayları. *Atatürk Üniversitesi Türkiyat Araştırmaları Enstitüsü Dergisi*, 4-9.

Goldstein, U. (1980). *An articulatory model for the vocal tracts of growing children* (Doctoral dissertation). Massachusetts Institute of Technology, Cambridge.

Gussenhoven, C., & Jacobs, H. (2011). *Understanding phonology.* Hodder Education.

Handbook of the International Phonetic Association. (1999). Cambridge: Cambridge University Press.

Harrington, J., & Cassidy, S. (1999). *Techniques in speech acoustics.* Dordrecht: Kluwer Academic Publishers.

Harris, J. (1983). *Syllable structure and stress in Spanish.* Cambridge, MA: MIT Press.

Harris, J. (1994). *English sound structure.* London: Blackwell.

Harris, J., & Lindsey, G. (1995). The elements of phonological representation. In J. Durand, & F. Katamba, *Frontiers of Phonology* (pp. 34-79). London and New York: Longman.

Harshman, R., Ladefoged, P., & Goldstein, L. (1977). Factor analysis of tongue shapes. *Journal of the Acoustical Society of America*, *62*(3), 693-713.

Hatipoğlu, Ç. (2002). Sesbilgisi (phonetics) ve sesbilim (phonology). In Ç. Hatipoğlu, *Dilbilim, Temel Kavramlar Sorunlar Tartışmalar* (pp. 15-42). Ankara: Dil Derneği.

Hayes, B. (2009). *Introductory phonology.* Malden, MA: Wiley-Blackwell.

Hayward, K. (2014). *Experimental phonetics.* London: Routledge.

Heine, B. (1975). Ik: eine ostafrikanische Restsprache. *Afrika und Übersee, 59*, 31-56.

Hillenbrand, J. M., Getty, L. A., Clark, M. J., & Wheeler, K. (1995). Acoustic characteristics of American English vowels. *Journal of the Acoustical Society of America, 97*(5), 3099–3111.

Jackson, M. (1988). *Phonetic theory and cross-linguistic variation in vowel articulation* (Doctoral dissertation). University of California, Los Angeles.

Jameson, K. A., & Alvarado, N. (2003). Differences in color naming and color salience in Vietnamese and English. *Color Research and Application, 28*(2), 113-138.

Jensen, J. T. (2004). *Principles of generative phonology: An introduction.* Philadelphia: John Benjamins Publishing Company.

Johnson, K. (1990). Contrast and normalization in vowel perception. *Journal of Phonetics, 18*(2), 229-254.

Johnson, K. (2003). *Acoustic and auditory phonetics.* Wiley-Blackwell.

Jones, D. (1966). *The pronunciation of English.* Cambridge: Cambridge University Press.

Karahan, L. (1996). *Anadolu ağızlarının sınıflandırılması.* Ankara: Türk Dil Kurumu.

Kaya, G., Öztürk, C., Yılgör, A., Altun, N., & Selimhocaoğlu, B. (2005). *Türk Dili Ders Notları.* İstanbul: Boğaziçi Üniversitesi Yayınları.

Kaye, J., Lowenstamm, J., & Vergnaud, J. (1985). The internal structure of phonological elements: A theory of charm and government. *Phonology Yearbook, 2*(1), 305-328.

Kaye, J., Lowenstamm, J., & Vergnaud, J. (1990). Constituent structure and government in phonology. *Phonology, 7*(2), 193-231.

Kenstowicz, M. J., & Kisseberth, C. W. (1979). *Generative phonology: Description and theory.* New York: Academic Press.

Kent, R. D. (1993). Vocal tract acoustics. *Journal of Voice, 7*(2), 97-117.

Kent, R. D., & Kim, Y. (2008). Acoustic analysis of speech. In M. J. Ball, M. R. Perkins, N. Müller, & S. Howard (Eds.), *The handbook of clinical linguistics* (pp. 360-380). Blackwell Publishing.

Labrune, L. (2012). *The phonology of Japanese.* Oxford: Oxford University Press.

Ladefoged, P. (1964). *A phonetic study of West African languages: An auditory-instrumental survey.* Cambridge: Cambridge University Press.

Ladefoged, P. (2001). *Vowels and consonants: An introduction to the sounds of languages.* Oxford: Blackwell.

Ladefoged, P., & Harshman, R. (1979). Formant frequencies and movements of the tongue. In B. Lindblom, & S. Öhman (Eds.), *Frontiers of speech communication* (pp. 25-34). New York: Academic Press.

Ladefoged, P., & Johnson, K. (2010). *A course in phonetics.* Boston: Wadsworth/Cengage Learning.

Ladefoged, P., & Maddieson, I. (1996). *The sounds of the world's languages.* Oxford: Blackwell.

Laufer, A., & Condax, l. D. (1981). The function of the epiglottis in speech. *Language and Speech*, *24*(1), 39-61.

Lindau, M. (1979). The feature expanded. *Journal of Phonetics*, *7*(2), 163-176.

Lindsey, G. (2013). *The vowel space*. Retrieved from https://www.englishspeechservices.com/blog/the-vowel-space/

Lindsey, G. (2017). Charting the vowel space. In G. Lindsey, & A. Nevins (Eds.), *Sonic signatures* (pp. 133-144). Philadelphia: John Benjamins Publishing Company.

Lobanov, B. (1971). Classification of Russian vowels spoken by different listeners. *Journal of the Acoustical Society of America, 49*, 606-608.

Maddieson, I. (1984). *Patterns of sounds.* Cambridge: Cambridge University Press.

Martínez-Celdrán, E. (2004). Problems in the classification of approximants. *Journal of the International Phonetic Association, 34*(2), 201-210.

McCloy, D. R. (2016). PhonR: Tools for phoneticians and phonologists. R package version 1.0-7.

Miller, W. R. (1966). *Acoma grammar and texts.* Berkeley, Los Angeles: University of California Press.

Navarro, T. (1918). *Manual de pronunciación española.* Madrid.

Nishi, K., Strange, W., Akahane-Yamada, R., Kubo, R., & Trent-Brown, S. A. (2008). Acoustic and perceptual similarity of Japanese and American English vowels. *The Journal of the Acoustical Society of America, 124*(1), 576-588.

Nişanyan, S. (2017, October 9). Retrieved from https://www.nisanyansozluk.com/?k=çömez&lnk=1

Odden, D. (2013). *Introducing phonology.* New York: Cambridge University Press.

Özsoy, S. (2004). *Türkçe'nin yapısı- 1 sesbilim.* İstanbul: Boğaziçi Üniversitesi Yayınevi.

Özünlü, Ü. (1984). Functional notions of Turkish verbal adjectives in adjective constructions. *Hacettepe Üniversitesi Edebiyat Fakültesi Dergisi, 2*(2).

Paramei, G. V., D'Orsi, M., & Menegaz, G. (2014). 'Italian blues': A challenge to the universal inventory of basic colour terms. *Journal of the International Colour Association, 13*, 27-35.

Prince, A., & Smolensky, P. (2004). *Optimality theory: Constraint interaction in generative grammar.* Oxford: Blackwell.

Raphael, L. J., Borden, G. J., & Harris, K. S. (2011). *Speech science primer: Physiology, acoustics, and perception of speech* (6th ed.). Philadelphia: Lippincott Williams & Wilkins.

Ray, P. S. (1967). Dafla phonology and morphology. *Anthropological Linguistics, 9*, 9-14.

Recasens, D., & Espinosa, A. (2005). Articulatory, positional and coarticulatory characteristics for clear /l/ and dark /l/: Evidence from two Catalan dialects. *Journal of the International Phonetic Association, 35*(1), 1-25.

Roach, P. (2009). *English phonetics and phonology: A practical course.* Cambridge: Cambridge University Press.

Rogers, D., & d'Arcangeli, L. (2004). Italian. *Journal of the International Phonetic Association, 34*(1), 117-121.

RStudio Team. (2019). RStudio: Integrated Development for R. Boston, MA.

Russell, G. O. (1928). *The vowel, its psychological mechanism, as shown by x-ray.* Columbus: Ohio State University Press.

Selen, N. (1979). *Söyleyiş sesbilimi, akustik sesbilim ve Türkiye Türkçesi.* Ankara: TDK Yayınları.

Stevens, K. N., & House, A. (1963). An acoustical theory of vowel production and some of its implications. *Journal of Speech and Hearing Research, 4*, 303-320.

Stevens, K. N., Kasowski, S., & Fant, G. (1953). An electrical analog of the vocal tract. *Journal of the Acoustical Society of America, 25*, 734-742.

Styler, W. (2017, December 25). *Using PRAAT for linguistic research.* Retrieved from http://wstyler.ucsd.edu/praat//UsingPraatforLinguisticResearchLatest.pdf

The principles of the International Phonetic Association. (1949). London: Cambridge University Press.

Wells, J. (2009, June 3). ə [Blog post]. Retrieved from http://phonetic-blog.blogspot.com/2009/06/blog-post.html

Winawer, J., Witthoft, N., Frank, M. C., Wu, L., Wade, A. R., & Boroditsky, L. (2007). Russian blues reveal effects of language on color discrimination. *Proceedings of the National Academy of Sciences, 104*(19), 7780-7785.

Yavuz, H., & Balcı, A. (2011). *Turkish phonology and morphology.* Eskişehir: Anadolu University.

Yip, M. (2002). *Tone.* Cambridge: Cambridge University Press.

Zimmer, K., & Orgun, O. (1999). Turkish. In *Handbook of the International Phonetic Association.* Cambridge University Press.

Zsiga, E. C. (2013). *The sounds of language: An introduction to phonetics and phonology.* West Sussex: Wiley-Blackwell.

APPENDICES

APPENDIX I

WORDS USED IN THE STUDY

[a]	[ɑ]	[e]	[ɛ]	[ɯ]	[i]
saat	saat	çengel	çengel	kâğıt	ulvi
gâvur	ampul	pembe	pembe	tıbbi	kulis
kâr	kar	lanet	canıgönülden	kısmi	ümit
lanet	malum	kolej	düzen	canıgönülden	huni
kâğıt	haluk	ekol	göçmen	muzır	suşi
âlâ	âlâ	belgesel	belgesel	trol	tıbbi
laf	canıgönülden	Seul	döner	ısı	kısmi
alkol	faul	kolye			virüs
8	8	8	8	8	8

[o]	[o̧]	[ø]	[u]	[u̧]	[y]
ordu	golcü	kötü	gâvur	Seul	ümit
boyun	kolye	nöron	kulis	ulvi	kötü
coşku	loş	bonkör	huni	sulh	golcü
nöron	alkol	canıgönülden	ordu	ampul	virüs
sol (L)	sol (g)	göçmen	suşi	haluk	canıgönülden
bonkör	hol	ödül	boyun	faul	düzen
kolej	ekol	döner	coşku	malum	modül
modül	trol	göl	muzır	ful	ödül
8	8	8	8	8	8

APPENDIX III

ETHICS COMMITTEE APPROVAL

Tarih: 04/05/2020
Sayı: 35853172-300-E.00001085607
0001085607

T.C.
HACETTEPE ÜNİVERSİTESİ
Rektörlük

Sayı : 35853172-300
Konu : Göktuğ BÖRTLÜ (Etik Komisyon İzni)

SOSYAL BİLİMLER ENSTİTÜSÜ MÜDÜRLÜĞÜNE

Enstitünüz İngiliz Dil Bilimi Anabilim Dalı yüksek lisans programı öğrencilerinden **Göktuğ BÖRTLÜ**'nün **Dr. Öğr. Üyesi Zeynep DOYURAN** danışmanlığında yürüttüğü **"Türkçenin Sesbilgisel ve Sesbilimsel Dökümü: Deneysel Bir Çalışma"**" başlıklı tez çalışması Üniversitemiz Senatosu Etik Komisyonunun **21 Nisan 2020** tarihinde yapmış olduğu toplantıda incelenmiş olup, etik açıdan uygun bulunmuştur.

Bilgilerinizi ve gereğini saygılarımla rica ederim.

e-imzalıdır
Prof. Dr. Rahime Meral NOHUTCU
Rektör Yardımcısı

Evrakın elektronik imzalı suretine https://belgedogrulama.hacettepe.edu.tr adresinden ceb4c47c-4282-4080-b121-3814da9da1fe kodu ile erişebilirsiniz.
Bu belge 5070 sayılı Elektronik İmza Kanunu'na uygun olarak Güvenli Elektronik İmza ile imzalanmıştır.

Hacettepe Üniversitesi Rektörlük 06100 Sıhhiye-Ankara
Telefon:0 (312) 305 3001-3002 Faks:0 (312) 311 9992 E-posta:yazimd@hacettepe.edu.tr İnternet
Adresi: www.hacettepe.edu.tr

Sevda TOPAL