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The Influence of Guttural Consonants /χ/, /ħ/, and /h/ on Vowel /a/ in Saudi Arabic

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Abstract

This paper presents a comparative study which investigates the influence of Saudi Arabic guttural consonants /χ/, /ħ/ and /h/ on the vowel /a/ when they are adjacent and in the same syllable. Cohn (2007, 2009), Flemming (2001), and Keating (1996) discuss a unified model in which phonology and phonetics are treated as two distinct elements of one domain where each element has an effect on the other to some degree. McCarthy (1991, 1994), Rose (1996), Zawaydeh (1999, 2004), and BinMuqbil (2006) presented phonological studies on gutturals, as well as discussions on gutturals as a natural class, which uphold the phonological aspect of Cohn's (2009) unified model. The aim of this study is to address the phonetic aspect of Cohn's (2009) unified model by analyzing the phonetic effects of guttural-vowel coarticulation. An acoustic analysis method was used as a framework for this investigation to extract first formant frequency (F1) and second formant frequency (F2) to measure the influence in the coarticulation. For the purpose of this study, seven native Saudi Arabic speakers were recorded pronouncing 70 Saudi Arabic words. The results showed that guttural consonants have an influence on the vowel /a/ by lowering and backing it when they are adjacent and in the same syllable, while the vowel /a/ in the nonguttural consonants is raising and fronting their adjacent vowel /a/ in the same syllable in comparison with the vowel /a/ in the guttural environment.

Keywords: [+low] vowel, [+back] vowel, guttural, phonetic-phonology interface

1. Introduction

Many linguists (Wright, 1964; Al-Ani, 1970; Brame, 1971; Ghazeli, 1977; Al-Sweel, 1987; Al-Mozainy, 1981; Abd-el Jawad, 1991; McCarthy, 1991, 1994; Yeou, 2001; Watson, 2002; Zawadeh, 2004; Bin-Muqbil, 2006; Al-Tamimi, 2007) have studied the phonological and sound systems of Arabic and its dialects in general, as well as the gutturals (Note 1) in specific. They found that gutturals in Standard Arabic and its dialects show phonological regularity such as (a) avoiding two gutturals in one syllable, (b) failing to occur in the coda position while there is no onset, and (c) spreading the [+low] feature by changing a [+high] vowel into [+low] vowel. This regularity provides evidence and support for the argument that *guttural* is a natural class. Keating (1990) discussed the interface between phonetics and phonology and referred to the lack of a phonetic study on the gutturals in Standard Arabic. Thus, the research presented in this paper aims to build on previous research by acoustically investigating the influence of guttural consonants on vowels in Saudi Arabic.

Cohn (2007, 2009), Flemming (2001), and Keating (1996) investigated and discussed the challenge of the phonetic-phonology interface. They agreed that there is one domain in which phonetics and phonology are two distinct approaches that interface. In this domain, phonetics affects phonology and vice versa. They also mentioned that phonetic is not only gradient, but could also be a categorical, while phonology could be both categorical and gradient. They provided some evidence for their assumption, such as coarticulation, assimilation, and vowel reduction. These authors presented a unified model which aims to map the effects phonetics and phonology has on each other.

In this paper, research is presented which builds on the phonological studies of [gutturals] as a natural class by measuring the coarticulation effect in a guttural environment. Here, I am not providing a connection between phonetics and natural class, but the results of this study (i.e., a phonetic study) and earlier phonological studies are similar but not the same, which could lead us to a unified view of guttural consonants in Standard Arabic. The acoustic analysis method is used to provide evidence for the natural class [guttural]. In this paper, the phoneme system of Saudi Arabic is presented in Section 2. In Section 3 the relevant literature is reviewed. Section 4 presents the methodology used in studying the influence of guttural consonants on the vowel /a/. Section 5 presents and discusses the results of my acoustic measurement research. Finally, in Section 6, the study is summarized and concluded.

2. Phoneme System of Saudi Arabic

Saudi Arabic has a large inventory of consonants as well as three vowels: /a/, /i/, and /u/. Saudi Arabic is rich with guttural consonants which are ʔ, h (the laryngeal), ʕ,ħ (the pharyngeal),and ʁ,χ (the uvular) (Ryding, 2005; Watson, 2002). Saudi Arabic has the most of Modern Standard Arabic's consonants inventory, such as the guttural consonants. Saudi Arabic has 31 phonemes with nine different locations of articulation. Twenty-six of these phonemes are consonants, of which two (/j/ yaa ي and /w/ waaw و) act in some conditions as semivowels and in other conditions as consonants. There are three vowels: /a/, /i/, and /u/ (Ryding, 2005). Table 1 and Figure 1 display the phoneme system of Saudi Arabic.

Table 1. The consonant phonemes of Saudi Arabic

	Bilabial	Labio-dental	Inter-dental	Dental-alveolar	Palatal	Velar	uvular	pharyngeal	Laryngeal
Stops	b			t d		k	q		ʔ
Emphatic				tˤ dˤ					
Fricatives		f	θ ð	s z	ʃ ʒ		χ ʁ	ħ ʕ	h
Emphatic			ðˤ	sˤ					
Nasal	m			n					
Lateral				l					
Trill				r					
Approximant					j	w			

Note. Bin-Muqbil, 2006; Watson, 2002; Yeou, 2001.

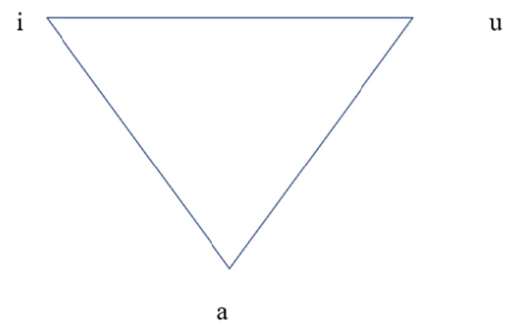

Figure1. The vowel Phonemes triangle of Saudi Arabic

Note. Bin-Muqbil, 2006; Newman & Verhoeven, 2002; Watson, 2002; Yeou, 2001.

3. Review of Relevant Literature

3.1 Phonetics-Phonology Interface

The relation between phonetics and phonology has been seen and understood as the quantitative-qualitative interface (Cohn, 2007, 2009). The relation between phonetics and phonology has undergone various stages. Ohalla (1990) and Hale and Peiss (2000) claimed that there is no interface between phonetics and phonology because phonetics is about computation and phonology is about abstract units. Browman and Goldstein (1995) and Blevins (2004) argued that there is a relationship between phonetics and phonology. They stated that phonetics affects sound change but does not systematize the sound pattern.

On the other hand, Keating (1990, 1996), Cohn (1998, 2007), Flemming (1997, 2001), and Chitoran and Cohn (2009) argued that the relationship between phonetics and phonology is that of two distinct approaches belonging to the same domain. They concluded that the two distinct approaches can be exhibited as the correlation between phonetics and phonology, on one hand, and the gradient and categorical entities, on the other hand. They stated that being in the same domain that does not mean phonetics and phonology are the same, only that they are similar.

Coarticulation and assimilation are evidence of the relationship between phonetics and phonology. For example, fronting of vowels by coronals has been studied as assimilation in phonology; however, it has also been studied from the phonetic perspective, and the results show that the degree of fronting of vowels by coronals differs between languages and sometimes even in the same language (Flemming, 2001). Keating (1996) discussed how velar fronting before front vowels can be both a phonological rule and a phonetic interpolation.

For the research presented in this paper, Flemming's (2001) and Chitoran and Cohn's (2009) unified model of phonetics and phonology, which claims the two are similar yet distinct has been adopted. Their unified model is based on mapping the effects of phonological patterns in phonetics and the effects of phonotactic patterns in phonology.

3.2 Phonological Studies on Gutturals

During the past two decades, phonological studies on gutturals in Standard Arabic and its dialects (Hebrew and Salish languages) have been conducted by linguists (McCarthy, 1991, 1994; Rose, 1996; Zawaydeh, 1999, 2004; Bin-Muqbil, 2006). These authors concluded that gutturals have specific features which support [guttural] as a natural class. These phonological patterns are:

- No gemination in gutturals.
- Avoid coda position.
- Vowel lowering in guttural syllables.
- Vowel-vowel harmony in guttural context (In some Arabic dialects, but not in the Standard Arabic (SA)).
- Avoid two gutturals in the same syllable (i.e., co-occurrence restriction).

Thus, from earlier phonological studies, gutturals can be seen as behaving as one group or one domain, which satisfies the first part of Chitoran and Cohn's (2009) and Flemming's (2001) unified model. In the next section, the second part of this model is addressed with my research on the phonetic changes in guttural-vowel coarticulation.

4. Methodology

The influence of guttural consonants /χ/, /ħ/ and /h/ and nonguttural consonants on the adjacent vowel /a/ in the same syllable was investigated in this study. To achieve this goal, acoustic analysis to measure and analyze the first formant frequency (F1) and the second formant frequency (F2) to determine the influence in the coarticulation was employed.

The focus of this research is to provide an in-depth analysis by analyzing only three voiceless gutturals: /χ/, /ħ/ and /h/. In addition, since the aim of this study is to provide in-depth understanding of the phenomena rather than generalized claims, the number of participants was limited to only 7 speakers (Note 2). The seven participants are native Saudi Arabic speakers (Najdi Arabic), and all participants gave their consent to participate in this study.

The data include recording 70 words–60 words in a guttural environment and 10 words in a nonguttural environment (hint: the non-guttural consonants are /k/, /n/, /s/, /f/, /r/, and /l/). More specifically, 10 words are in χVC position, 10 words are in CVχ position, 10 words are in ħVC position, 10 words are in CVħ position, 10 words are in hVC position, and 10 words are in CVh position. For the non-gutturals, 10 words are tested in CVC position (for more information regarding the data used please see appendix A).

For the purposes of this study, the participants were asked to articulate the Saudi Arabic words. These words were articulated three times each in the following context:

- qul _____ marra θanya
- English translation: 'say ____ again'

Three articulations were used in order to increase the naturalistic articulation of the tested words and to decrease speakers' bias. For this study, I used a *Zoom H4N Handy Audio Recorder* to record the first speaker's 70 examined words. The recording session was done in the Linguistic Department Laboratory at Eastern Michigan University. For the second speaker, I used a *Sony ICD-AX412 Stereo Digital Voice Recorder* to record the 70 examined words. The recording session was done in my apartment. All of the audio files are in WAV format. For measuring the tested articulations, I used Praat software, which automatically extracts the formant frequencies (i.e., F1 and F2) (Boersma & Weenink, 2001). The settings used with the Praat software were the default settings of 0.0 second time step, a maximum formant frequency of 5000 (Hz), a maximum of 5 formants, a window length of 0.025 second, and a dynamic range of 30 (dB).

Guttural consonants are distinguished from nonguttural consonants by having one or both of these features [low] and [back] switched ON (Chomsky & Halle, 1968; Halle, 1983). Using this distinction, my research measures the mean of the F1 and the F2 of vowel /a/ in the same syllable as a guttural consonant and adjacent to it. Flanagan (1955) described the F1 of a vowel as a representation of the position of the vowel on the high-low dimension, while the F2 is a representation of the position of the vowel on the front-back dimension. Table 2 illustrates the interpretation of F1 and F2. Figure 2 shows the interpretation of F1 and F2 on IPA vowels. This figure was posited by Hayes (2013) and explains the F1 and F2 in practical terms.

Table 2. The interpretation of formant frequency on vowels

Formant Frequency	Interpretation on Vowel
F1 = high frequency	Low vowel e.g. /a/
F1 = low frequency	High vowel e.g. /i/
F2 = high frequency	Front vowel e.g. /i/
F2 = low frequency	Back vowel e.g. /u/

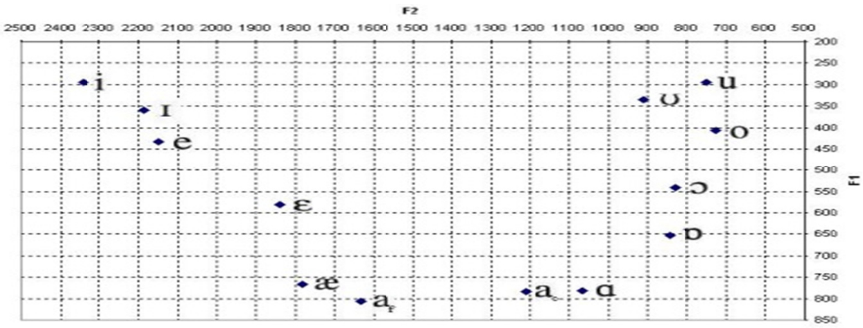

Figure 2. The interpretation of F1 and F2 on IPA vowels (Bruce Hayes, 2013)

As illustrated in Table 2 and Figure 2, when the F1 of vowel *x* is high, vowel *x* lowers and acquires the [+low] feature. Furthermore, when the F1 of vowel *x* is low, vowel *x* raises and shows the [-low] feature. Conversely, when the F2 of vowel *x* is high, vowel *x* is in the front position of Hayes' figure. Furthermore, when the F2 of vowel *x* is low, vowel *x* is in the back position. Therefore, this research measures the F1 and F2 of the adjacent vowel of the guttural and nonguttural consonants to find out if there is a coarticulation effect of guttural consonants on their adjacent vowel in the same syllable by lowering and/or backing it.

5. Results and Discussion

The findings of this study derive into the form of the mean of the first formant frequency (F1) and the second formant frequency (F2) in the initial and midpoint position of the adjacent vowel in the same syllable of guttural and nonguttural consonants in the three times of articulation. The total mean of F1 and F2 in the initial and midpoint position of each consonantal group was calculated in this study. Furthmore, the result of the t-test is given.

For the purpose of this study, a comparison was made between the backward (L-R) and forward (R-L) coarticulation based on the frequency of the F1 and F2 of the initial and midpoint position of the vowel /a/ in a guttural context. Furthermore, the aim of this comparison was to find if the gutturals have an effect on the vowel /a/ in L-R and R-L coarticulation. The initial and midpoint positions of the vowel would show the effect of the consonants on the vowel /a/. Also, I compared between the effect of the F1 formant and F2 formant in gutturals context with nonguttural. This comparison would help to clarify the picture of the [guttural] as a natural class. To sum up, this study presents/investigates in three levels of comparison:

In this study, it was found that the total mean of the first formant frequency (F1) of the adjacent vowel /a/ in the same syllable of the guttural consonants by the seven speakers is higher than the first formant frequency (F1) of following vowels /a/ of the nonguttural consonants, which means that guttural consonants have an effect on their adjacent vowels by lowering them. Furthermore, the total mean of the second formant frequency (F2) of the adjacent vowel /a/ of the guttural consonants is lower by the 7 speakers than the adjacent vowel /a/ of the nonguttural consonants, which would be interpreted as guttural consonants having an influence on their adjacent by backing them. Tables 3–6 show the total mean of the averages of F1 and F2 of the adjacent vowel /a/ in guttural and nonguttural environments by the 7 speakers.

Table 3. The mean of F1 formant of /a/ in the initial and midpoint position, in guttural and nonguttural context, and in L-R coarticulation

	χVC		ħVC		hVC		Nonguttural	
	Initial 1	Midpoint 2	Initial 1	Midpoint 2	Initial 1	Midpoint 2	Initial 1	Midpoint 2
F1	688	673	726	674	688	666	505	580
	Total mean of /a/ in all initial positions			Total mean of /a/ in all midpoint positions			Total mean of /a/ in all initial and midpoint positions	
	700			671			505	580
Total mean of F1 /a/	685						542	
t-test	3.65463. The p-value is .000388. The result is significant at p < .05							

Table 3 shows a comparison between the effect of gutturals on the initial and midpoint frequencies of the F1 of the vowel /a/ in backward (L-R) coarticulation; it also shows a comparison between the effect of gutturals and non-gutturals on their adjacent vowel /a/. First, the findings in Table 3 show that there is an effect of gutturals on their adjacent vowel /a/ in the same syllable. Also found is that the L-R coarticulation effect could be seen higher in the initial position in comparison with the midpoint position in guttural context. Furthermore, Table 3 shows a comparison between the effect of gutturals and non- gutturals on the F1 frequency of the vowel /a/, and I found that gutturals have a higher effect on the initial and midpoint positions in comparison with the non-gutturals. Gutturals in L-R coarticulation have a higher effect on initial position than on the midpoint position by lowering initials more than the midpoint. Also, gutturals in L-R coarticulation have a higher effect on their adjacent vowel /a/ by lowering it more than the vowel /a/ in non-gutturals. Also, the t-test came out that the vowel in guttural context are affected significantly than in non-guttural context. Next to be considered is Table 4, or forward coarticulation.

Table 4. The mean of F1 formant of /a/ in the initial and midpoint position, in guttural and nonguttural context, and in R-L coarticulation

	CVχ		CVħ		CVh		Nonguttural	
	Initial 1	Midpoint 2	Initial 1	Midpoint 2	Initial 1	Midpoint 2	Initial 1	Midpoint 2
F1	599	600	605	682	563	644	505	580
	Total mean of /a/ in all initial positions			Total mean of /a/ in all midpoint positions			Total mean of /a/ in all initial and midpoint positions	
	589			642			505	580
Total mean of F1 /a/	615						542	
t-test	-2.26682. The p-value is .014588. The result is significant at p < .05							

Table 4 shows a comparison between the effect of gutturals on the initials and midpoints in forward (R-L) coarticulation. Also, it shows a comparison between the effect of gutturals and non-gutturals on the F1 of the adjacent vowel /a/. This research found that in forward coarticulation (R-L coarticulation) the midpoint position of the vowel /a/ has been affected by the gutturals more than the initial position. Same as in Table 3, the gutturals in coda position show that they significantly affect their adjacent/following vowel than the non-gutturals. The total mean of the midpoint of the vowel /a/ is 642 Hz, while the total mean of the initial position of the vowel /a/ is 589 Hz. This means that midpoint is lower than the initial position and this is because of guttural coarticulation. Furthermore, as shown in Table 5, the gutturals have a higher effect on the vowel /a/ than do the non-gutturals. The total mean of the F1 formant of the vowel /a/ in a guttural context is 615 Hz while it is 542 Hz in a nonguttural context, which means that gutturals have lowered the F1 of the /a/ more than the non-gutturals have done with the F1 of the vowel /a/.

Table 5. The mean of F2 formant of /a/ in the initial and midpoint position, in guttural and nonguttural context, and in R-L coarticulation

	CVχ		CVħ		CVh		Nonguttural	
	Initial 1	Midpoint 2	Initial 1	Midpoint 2	Initial 1	Midpoint 2	Initial 1	Midpoint 2
F2	1384	1212	1463	1430	1336	1333	1645	1584
	Total mean of /a/ in all initial positions			Total mean of /a/ in all midpoint positions			Total mean of /a/ in all initial and midpoint positions	
	1394			1325			1645	1584
Total mean of F2 /a/	1359						1614	
t-test	-3.57029. The p-value is .000493. The result is significant at $p < .05$							

Table 5 in this study shows the effect of gutturals in forward (R-L) coarticulation on the initial and midpoint of the F2 formant of the vowel /a/. Also, this table shows the effect of gutturals and non-gutturals in R-L coarticulation on the F2 formant of the adjacent vowel /a/. The findings show that midpoint positions of the vowel /a/ in forward coarticulation have low values in comparison with the values of initial positions. This means that, in forward coarticulations, gutturals have an effect on the midpoint positions by backing the midpoint position because it is closer to the guttural than the initial position to the gutturals. Also, this table shows that gutturals have a higher effect on the vowel /a/ by backing the vowel /a/ more than the non-gutturals did with the vowel /a/. The total mean of the F2 of the /a/ in guttural context is 1359 Hz, while the total mean of the F2 of the vowel /a/ in nonguttural context is 1614 Hz, which means that the vowel /a/ in guttural context is sitting in the back of Hayes' Figure (2013) (i.e., Figure 2) while the vowel /a/ in a nonguttural context is sitting in the front of Hayes' Figure (2013).

Table 6. The mean of F2 formant of /a/ in the initial and midpoint position, in guttural and nonguttural context, and in L-R coarticulation.

	χVC		ħVC		hVC		Nonguttural	
	Initial 1	Midpoint 2	Initial 1	Midpoint 2	Initial 1	Midpoint 2	Initial 1	Midpoint 2
F2	1253	1295	1408	1362	1418	1451	1645	1584
	Total mean of /a/ in all initial positions			Total mean of /a/ in all midpoint positions			Total mean of /a/ in all initial and midpoint positions	
	1359			1369			1645	1584
Total mean of F2 /a/	1364						1614	
t-test	-5.43978. The p-value is < .00001. The result is significant at $p < .05$							

Table 6, as in the previous tables, shows a comparison between the effect of gutturals in backward (L-R) coarticulation on the F2 formant of the initial and midpoint positions of the vowel /a/. Also, this table shows a comparison between the effect of gutturals and non-gutturals on the F2 formant of the vowel /a/ in backward coarticulation. The results, as in previous tables, show that gutturals always have a high effect on the closest position of the vowel /a/ to gutturals, and in this table the initial position is the closest position of the vowel to the gutturals. The comparison between the initial and midpoint position of the F2 formant of the vowel /a/ in L-R coarticulation shows that gutturals have an effect on the initial positions more than on the midpoint positions. Also, Table 6 shows that the value of the F2 formant of the vowel /a/ in a guttural context is low in comparison with the value of F2 of /a/ in nonguttural contexts, which means that the guttural is backing the vowel /a/ more than the non-gutturals are. F2 of gutturals in onset or coda positions has the same affects as the F1which shows that guttural significantly influence their following vowel /a/ than their count part non-gutturals do.

Figure 3 shows the mean of the F1 and F2 formant of the adjacent vowel /a/ in the same syllable in initial and midpoint position, in guttural and nonguttural context, and in forward (R-L) and backward (L-R) coarticulation.

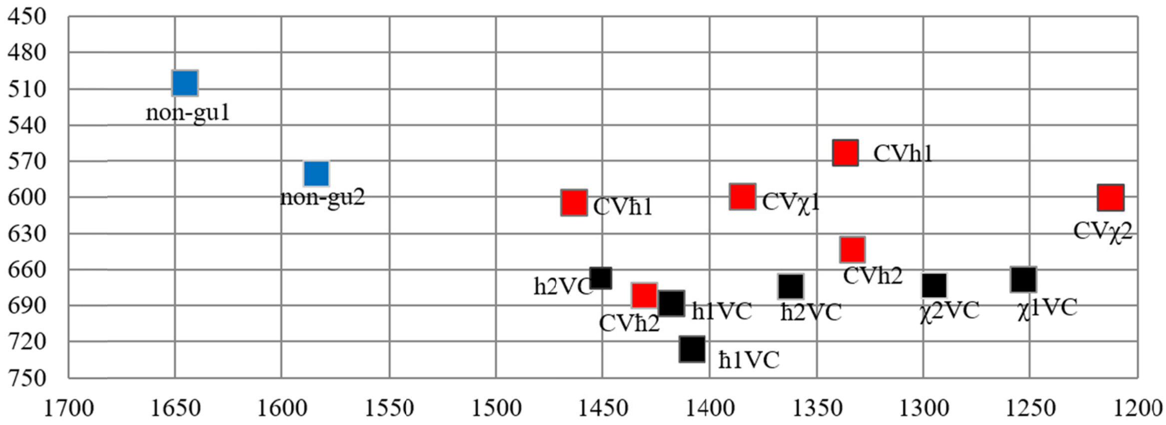

Figure 3. The mean of F1 and F2 formant of /a/ in the initial and midpoint positions, in guttural and non-guttural contexts, and in R-L & L-R coartiulation

It is obvious from Figure 3 that the guttural consonants have a higher effect on the vowel /a/ than the nonguttural consonants by lowering and backing it. In comparison between the forward and backward coarticulations (i.e., CVG and GVC), we can find that gutturals also have the higher impact on the closest position of the vowel /a/ to the gutturals by lowering and backing it. In the GVC context, the gutturals always move the initial position of the vowel /a/ to a lower and backer position than the midpoint position vowel /a/, which is closer to the nonguttural consonant. On the other hand, the midpoint of the vowel /a/ in the CVG context appears to be lower and backer than the initial position of the vowel /a/ because the midpoint of /a/ is closer to the guttural than the initial position.

To sum up, the findings in previous Tables 4–7 and Figure 3 proved to us that gutturals have a phonotactic effect as well as the phonological effect by lowering and backing the value of the vowel /a/. Also, the findings show that the value of the vowel /a/ has been changed significantly based on the place of the gutturals. If the gutturals are in coda position, the midpoint of the vowel would be more affected than the initial position and vice versa. Finally, the findings have not showed any significant results within gutturals or within non-gutturals.

6. Conclusion

This paper presented my findings and analysis of the phonetic influence the Saudi Arabic guttural consonants /χ/, /ħ/, and /h/ have on the vowel /a/ when they are adjacent and in the same syllable. In this study acoustic analysis was used to obtain two measurements: 1) the mean of the first formant frequency (F1) to determine the position of the vowel on the high-low dimension, and 2) the mean of the second formant frequency (F2) to determine the place of articulation of the vowel on the front-back dimension. In this paper the findings are presented that the guttural consonant lowers the adjacent vowel /a/ while the nonguttural consonants do not, and that the guttural consonants also affect the adjacent vowel /a/ by backing or centralizing it while nonguttural consonants do not.

This study also builds on previous phonological research on [guttural] as a natural class, as well as provides acoustic and phonetic evidence that Saudi Arabic supports the phonological studies such as those of Hayward and Hayward (1989), McCarthy (1991, 1994), BinMuqbil (2006), and SylakGlassman (2013, 2014) which argued for [guttural] to be classified as a natural class.

In this study only the voiceless gutturals and their influence on the vowel /a/ were analyzed. Further study covering all the gutturals—voiced and voiceless—should be conducted. Also, this study tested the influence of gutturals on only the vowel /a/ in Saudi Arabic. More studies should be done that analyze the phonetic effect of gutturals on the vowels /i/ and /u/. Finally, I suggest that there should be an acoustic analysis study done on the pharyngealized consonants to investigate their phonetic process of coarticulation and compare them with guttural consonants. This would help to build and clarify the phonetic theory and sound system.

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Notes

Note 1. There are two definitions of gutturals, but this paper defines gutturals as consonants located in the post-velar position (i.e. uvular, pharyngeal, and laryngeal). Also, this paper adopts the label [guttural] as a natural class for these consonants.

Note 2. The results from /χ, ħ and h/ generalize to the whole class.

Appendix A

The Data used

Table 7. The mean of F1 formant of /a/ in the initial and midpoint position, and in guttural and nonguttural context

Word	F1 1st		F1 2nd		F1 3rd		Mean	
	Initial	midpoint	initial	midpoint	initial	midpoint	initial	midpoint
/ħ/ in CVCVħ								
1. malaħ	617	658	631	712	615	688	621	686
2.fallaħ	600	650	615	693	649	712	621	685
3. ʒaraħ	578	681	610	748	606	763	598	730
4. silaħ	605	651	595	661	595	625	598	645
650	598	656	601	626	613	668	604	
6. nubaħ	570	618	561	623	588	631	573	624
7. safaħ	606	633	621	647	630	677	619	652
8. tufaħ	593	628	595	619	605	632	597	626
9. Sajaħ	619	624	592	640	607	634	606	632
10. sujaħ	611	634	603	637	575	604	596	625
Total mean							**603**	**655**
/ħ/ in CVħVC								
1. ʒuħar	797	726	749	686	814	778	786	730
2. daħar	789	720	746	681	819	769	784	723
3. saħar	810	706	756	701	793	751	786	719
4. laħħam	848	765	791	781	750	771	796	772
5. faħal	732	631	693	539	656	641	693	603
6. laħadˤ	767	656	814	643	794	696	791	665
7. ʔaħab	763	707	726	697	732	677	740	693
8. saħab	674	665	739	664	683	643	698	657
9. baħar	724	705	746	724	755	676	741	701
10. laħam	735	668	697	688	748	696	726	684
Total mean							**754**	**695**
/χ/ in CVχVC								
1.buχar	711	681	653	665	644	684	669	676
2.muχat	721	724	712	718	730	750	721	730
3.naχal	734	701	704	660	780	763	739	708
4.daχal	593	629	602	640	630	646	608	638
5.faχar	614	662	663	659	694	697	657	672
6.saχar	657	660	702	661	731	642	696	654
7.buχal	616	614	619	606	623	623	619	614
8.saχal	598	623	657	660	572	634	609	639
9. ʃaχas	661	612	531	521	577	558	589	563
10.zaχam	753	711	731	712	704	743	729	722
Total mean							**663**	**661**
/χ/ in CVCVχ								
1. baðaχ	563	619	561	587	574	613	566	606
2. taraχ	632	657	622	646	630	637	628	646
3. malaχ	617	704	673	714	590	631	626	683
4.tabaχ	523	585	593	631	612	650	576	622
5.suraχ	637	687	633	662	650	703	640	684
6.firaχ	596	668	612	692	611	689	606	683
7. ʃalaχ	645	712	603	690	618	689	622	697
8. salaχ	647	673	623	677	620	682	630	677
9.nasaχ	638	710	589	659	590	632	605	667
10.fasaχ	544	601	552	657	605	687	567	648
Total mean							**606**	**596**
/h/ in CVCVh								
1. hibah	488	591	561	628	539	645	529	621
2.surah	622	678	577	668	727	805	642	717
3. ħarah	669	763	643	648	636	673	649	694

4.tasah	692	508	639	786	586	686	639	660
5. ʃidah	489	616	561	602	491	629	513	615
6. hazah	468	588	388	523	397	585	417	565
7.waʒah	526	549	526	527	525	576	525	550
8.qarah	546	540	574	558	595	652	571	583
9.farah	597	623	617	609	641	709	618	647
10.kurah	603	683	582	627	604	665	596	658
Total mean							**570**	**631**
/h/ in CVh**V**C								
1. ʒihat	669	677	630	616	680	661	659	651
2.saham	704	707	703	697	720	687	709	697
3.nahar	744	685	743	735	687	677	724	699
4.mahar	708	636	687	666	705	688	700	663
5. ʃuhaq	606	594	659	663	645	623	636	626
6.kahaf	577	609	603	612	594	620	591	613
7.tuham	707	701	749	734	699	684	718	706
8.nuhaq	687	667	689	667	670	654	682	662
9. ʃahad	683	618	615	550	643	598	647	588
10.fahad	641	608	586	569	647	628	624	601
Total mean							**669**	**651**
/a/ in different environment other than pharyngeal CVC**V**C								
1.katab	506	543	536	552	549	581	530	558
2.naqal	600	606	622	627	632	627	618	620
3. ʒarab	553	586	562	589	623	588	579	587
4. ʃarab	583	609	609	608	603	617	598	611
5. ʃaka	588	653	513	604	517	641	539	632
6. safir	481	543	480	445	501	504	487	497
7. ʒalas	523	579	555	603	517	600	531	594
8. ʔarsal	477	548	439	545	491	584	469	559
9. banat	554	631	650	699	596	691	600	673
10.dalal	558	622	580	625	566	624	568	623
Total mean							**552**	**592**

Table 8. The mean of F2 formant of /a/ in the initial and midpoint position, and in guttural and nonguttural context

Word	F2 1st		F2 2nd		F2 3rd		Mean	
	Initial	midpoint	initial	midpoint	initial	midpoint	initial	midpoint
/ħ/ in CVC**V**ħ								
1. malaħ	1582	1520	1597	1556	1532	1545	1570	1540
2.fallaħ	1579	1556	1614	1593	1609	1564	1600	1571
3. ʒaraħ	1265	1353	1288	1333	1273	1322	1275	1336
4. silaħ	1654	1604	1688	1624	1696	1606	1679	1611
5. Sabaħ	1157	1302	1141	1190	1163	1249	1153	1247
6. nubaħ	1305	1503	1342	1524	1211	1407	1286	1478
7. safaħ	1500	1511	1523	1533	1528	1512	1517	1518
8. tufaħ	1438	1455	1450	1481	1431	1460	1439	1465
9. Sijaħ	1630	1563	1725	1600	1700	1545	1685	1569
10. sujaħ	1637	1550	1704	1628	1790	1715	1710	1631
Total mean							**1491**	**1496**
/ħ/ in CVħ**V**C								
1. ʒuħar	1490	1439	1481	1389	1501	1469	1490	1432
2. daħar	1510	1460	1490	1404	1505	1473	1501	1445
3. saħar	1513	1323	1347	1376	1416	1392	1425	1363
4. laħħam	1542	1448	1549	1422	1530	1475	1540	1448
5. faħal	1725	1685	1712	1707	1670	1708	1702	1700
6. laħadˁ	1407	1323	1455	1302	1427	1323	1429	1316
7. ʔaħab	1584	1605	1578	1509	1541	1513	1567	1542
8. saħab	1491	1472	1478	1383	1444	1392	1471	1415
9. baħar	1388	1365	1371	1319	1337	1332	1365	1338
10. laħam	1742	1715	1632	1558	1741	1714	1705	1662
Total mean							**1519**	**1446**
/χ/ in CVχ**V**C								
1.buχar	1264	1289	1226	1294	1200	1256	1230	1279

2.muχat	1262	1242	1249	1260	1590	1329	1367	1277
3.naχal	1505	1539	1473	1513	1487	1555	1488	1535
4.daχal	1467	1578	1507	1579	1417	1431	1463	1529
5.faχar	1250	1257	1267	1289	1279	1305	1265	1283
6.saχar	1344	1409	1318	1310	1276	1263	1312	1327
7.buχal	1514	1496	1462	1493	1551	1593	1509	1527
8.saχal	1295	1362	1347	1383	1239	1297	1293	1347
9. ʃaχas	1294	1312	1207	1149	1194	1194	1231	1218
10.zaχam	1330	1319	1322	1261	1331	1373	1327	1317
Total mean							**1348**	**1364**
/χ/ in CVC**V**χ								
1. baðaχ	1522	1494	1542	1541	1550	1644	1538	1559
2. taraχ	1465	1464	1365	1359	1394	1393	1408	1405
3. malaχ	1470	1488	1526	1509	1472	1518	1489	1505
4.tabaχ	1137	1186	1141	1179	1169	1220	1149	1195
5.suraχ	1251	1255	1223	1151	1286	1270	1253	1225
6.firaχ	1483	1394	1457	1408	1493	1416	1477	1406
7. ʃalaχ	1510	1496	1487	1470	1479	1527	1492	1497
8. salaχ	1287	1344	1232	1290	1217	1291	1245	1308
9.nasaχ	1605	1542	1533	1621	1544	1530	1560	1564
10.fasaχ	1604	1586	1468	1484	1541	1537	1537	1535
Total mean							**1415**	**1266**
/h/ in CVC**V**h								
1. hibah	1351	1449	1382	1473	1362	1436	1365	1452
2.surah	1291	1236	1258	1223	1232	1243	1260	1234
3. ħarah	1308	1278	1245	1248	1225	1187	1259	1237
4.tasah	1438	1188	1613	1545	1573	1492	1541	1408
5. ʃidah	1697	1655	1665	1710	1689	1629	1683	1664
6. hazah	1581	1554	1641	1627	1627	1634	1616	1605
7.waʒah	1182	1502	1219	1545	1116	1468	1172	1505
8.qarah	1260	1178	1194	1177	1179	1219	1211	1191
9.farah	1214	1253	1252	1238	1252	1238	1239	1243
10.kurah	1290	1233	1225	1201	1240	1189	1251	1207
Total mean							**1360**	**1374**
/h/ in CVh**V**C								
1. ʒihat	1603	1599	1563	1591	1647	1583	1604	1591
2.saham	1364	1303	1494	1472	1430	1396	1429	1390
3.nahar	1444	1475	1452	1439	1356	1357	1417	1423
4.mahar	1308	1285	1312	1327	1319	1301	1313	1304
5. ʃuhaq	1540	1555	1588	1579	1545	1510	1557	1548
6.kahaf	1621	1580	1608	1572	1564	1551	1597	1567
7.tuham	1334	1395	1376	1374	1426	1379	1378	1382
8.nuhaq	1645	1688	1587	1605	1614	1617	1615	1636
9. ʃahad	1640	1642	1710	1661	1682	1681	1677	1661
10.fahad	1591	1613	1626	1670	1638	1651	1618	1644
Total mean							**1520**	**1515**
/a/ in different environment other than pharyngeal CVC**V**C								
1.katab	1663	1570	1666	1589	1692	1669	1673	1609
2.naqal	1282	1492	1316	1228	1359	1465	1319	1395
3. ʒarab	1213	1286	1245	1242	1224	1279	1227	1269
4. ʃarab	1278	1256	1276	1291	1269	1265	1274	1270
5. ʃaka	1698	1591	1711	1583	1672	1449	1693	1541
6. safir	1791	1752	1685	1671	1715	1703	1730	1708
7. ʒalas	1583	1362	1598	1612	1562	1621	1581	1531
8. ʔarsal	1679	1655	1590	1642	1616	1651	1628	1649
9. banat	1602	1589	1596	1535	1653	1572	1617	1565
10.dalal	1622	1580	1578	1560	1622	1566	1607	1568
Total mean							**1530**	**1510**