Vowel Coarticulation in Zulu

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Abstract

In Zulu, a language spoken in South Africa, there is a group of sounds within consonants called clicks, which are categorized into three types: dental, lateral and palatal. This paper discusses the coarticulatory effect on vowels in environments that precede and follow clicks, especially palatal clicks. This paper provides a different perspective from that of previous studies on coarticulatory effects, which focused on pulmonic consonants. Through analyzing recordings of a native Zulu speaker using Praat and vowel plot, a coarticulatory effect was found in acoustic signals. F1 and F2 values showed differences of the effect between preceding vowels and following vowels caused by height, frontness, and roundness of vowels. Since the posture of the tongue, which is the tongue blade and the dorsum, is essential in producing clicks, it is expected that there is an "ease-of-articulation" effect on the adjacent vowels in order to pronounce sounds with ease.

1 Introduction

Zulu is a language spoken in South Africa, which is categorized as a Bantu language, specifically in the Nguni Group along with Xhosa and Swazi (Malcolm, xv). In Zulu, besides pulmonic vowels and consonants, there is a group of sounds within consonants called clicks. There are three types of clicks: dental click, represented with [|], lateral click, represented with [ǁ], and palatal click, represented with [!] (Thomas-Vilakati, 3). Generally, in terms of orthography, dental clicks are written with 'c', lateral clicks with 'x', and palatal clicks with 'q' (Malcolm, xvi). Other aspects of the clicks are represented with additional alphabets; for example, 'h' after clicks indicates aspiration, 'g' or 'ng' before clicks implies voicing, and 'n' before the clicks represents nasalization (Malcolm, xvi). Words with clicks include xuma [ǁùmà] "leap!", icici [i|i|ì] "an earring", and gqiba [!ʲbà] "fill up!"

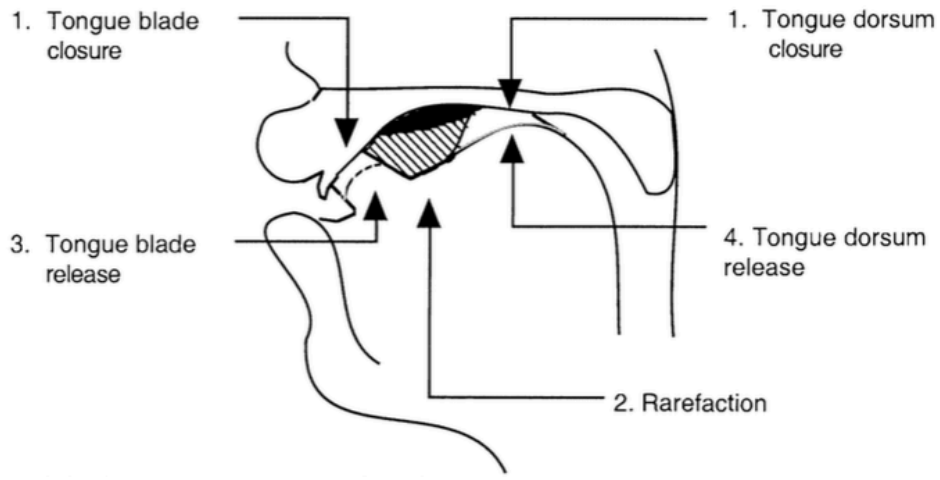
In this paper, I investigate the coarticulatory effect on vowels in environments that precede and follow click sounds, especially palatal clicks. This study will provide a different perspective from that of previous studies on coarticulatory effects, which focused on pulmonic consonants. Since articulatory settings are different between clicks and vowels, I hypothesize that there is a coarticulatory effect on vowels next to the palatal clicks, both proceeding and following the vowel. I will investigate whether this coarticulatory effect can be found in acoustic signals. The rest of the paper will discuss vowel coarticulation in the following order: 2. Literature Review, 3. Methods, 4. Acoustic analysis, 5. Discussions, and 6. Conclusion.

2 Literature Review

In *Coproduction and Coarticulation in IsiZulu* (1999), Thomas-Vilakati examines the coproduction difference of three clicks using three methods: static palatography and linguography, dynamic palatography, and aerodynamic records. He then provides evidence that click consonants are affected by the adjacent vowels. He states that a sealed cavity along the palate created by the tongue, and rarefaction of the tapped air are common factors found in production of all the click sounds together with similar closure durations (6). The front closure release and internal timing patterns differentiate the three clicks (7).

Figure 1 shows the steps of producing click sounds. Click sounds are created within a space in the mouth between front and back of the tongue. After both the tongue blade and the dorsum are raised to make closure, the air inside the space becomes rarefied by lowering the tongue dorsum (Thomas-Vilakati, 5). Then, the tongue blade and the dorsum are released one by one, and the click sound is produced (5).

Figure 1: Mechanism used in click production (Thomas-Vilakati, 5).



The author explains that coarticulation results from the place of constriction, and the movement of the tongue towards it (11). The major approach considered to be resulting in coarticulation of clicks is the "ease-of-articulation", since combining vowels and clicks is difficult (12). The author introduces Traill's (1985) study to show that the tongue center is in a higher position for palatal and dental clicks, compared to lateral and alveolar click which had low tongue center positions (14).

Thomas-Vilakati concludes, that because producing clicks involves the tongue body and the tongue blade, and producing vowels involves the tongue body, meeting the demands of both clicks and adjacent vowels in terms of the tongue body will be the key to understanding the coarticulation of clicks (15).

3 Methods

All of the data were collected by recordings of ZUL 001, which consist of utterances by a speaker pronouncing a list of words containing palatal click sounds. The speaker is a female in her late twenties from Durban, South Africa, and uses Zulu in private settings[1]. She does not have any illnesses or hearing disorders that would have affected her speech.

In addition to palatal clicks, the recordings were also collected for dental and lateral clicks. There was a particular environment in which the speaker could not produce words – where the lateral click was preceded by a plain vowel and followed by [i]. For instance, there are no cases such as [iǁi] and [uǁi]. The major difference between the palatal click and the lateral click is that the lateral click has lower tongue center positions, as mentioned in Thomas-Vilakati (1999).

4 Acoustic Analysis

4.1 *Data* From the five different types of vowels in Zulu, this study targets [i], [ɑ] and [u]: [i] is a high front unrounded vowel, [ɑ] is a low unrounded vowel, and [u] is a high back rounded vowel. The three vowels combine and generate 9 different environments in which palatal click consonant [!] can occur: [i_i], [i_u], [i_a], [u_u], [u_i], [u_a], [a_a], [a_i], and [a_u]. Each word is recorded three times in a row, resulting in a total of 27 tokens.

Table 1: Data set collected from recordings of ZUL 001.

	[i]	[ɑ]	[u]
[i]	isigqila [ísí!ɟìlà] "a slave"	iqanda [í!à^{n}dà] "an egg"	iqhude [ì!^{h}ùdè] "a rooster"

[1] English in South Africa is a business language although it is sometimes used privately. Private settings include conversations with family members and close friends.

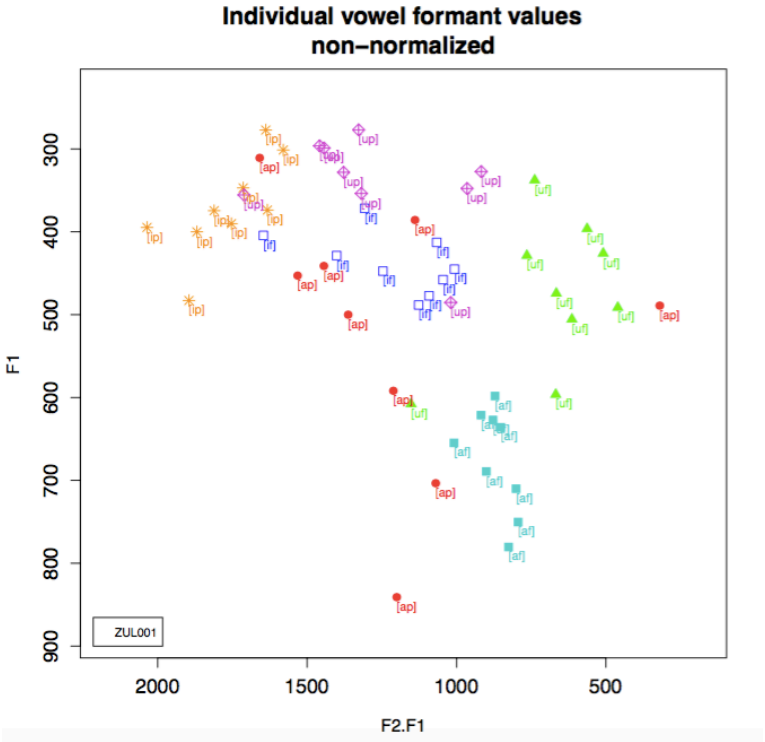
[ɑ]	aqinile [à!ìnìlè] “(people) hyperactive”	amaqanda [ámá!àⁿdà] “eggs”	aqubile [à!ùbìlè] “the one lay down in hiding”
[u]	uqinile [ú!ínìlè] “(person/animal) hyperactive”	fuqa [fù!á] “push!”	ukuqhuba [úkú!ʰùbà] “to drive along”

Table 1 shows the collected data with palatal clicks in different environments. The vertical rows represent the preceding vowels, whereas the horizontal rows represent following vowels. For example, ‘aqinile’ is designed to elicit the environment in which the palatal click is preceded by [ɑ], and followed by [i].

For both preceding and following vowels, the first and the second formants were recorded using the formant listing function of Praat. Each of the formants were calculated by averaging the closest and the second-to-the-closest value to the interval boundaries, so the final two formants were averaged for the preceding vowel, and the first two formants were averaged for the following vowel.

4.2 *Results* Acoustic measurements are used to quantify the patterns of the vowel coarticulation. The individual and the averaged formant values are shown on Table 2 created on Excel. Figure 2 is created using the Vowel Norminalization Suite NORM. In this figure, the y-axis is the F1 value, and the x-axis is the difference in value between F2 and F1. The positions of the occurrence of vowels are indicated by either “p” or “f” after each vowel: “p” represents preceding, and “f” represents following. In addition to these letters, all six combinations of different vowels and positions of occurrence are plotted with different symbols. Preceding-[i] is represented with *, following-[i] is represented with , preceding-[ɑ] is represented with ●, following-[ɑ] is represented with , preceding-[u] is represented with ◇, and following-[u] is represented with ▲.

Figure 2: Vowel plot created by F1 and F2.



Contextual differences of the three vowels manifest themselves in this plot; therefore, it can be said that there is a coarticulatory effect of palatal clicks on vowels. Comparing the combinations of vowels in different environments, preceding-[ɑ] show large variability because of the wide range in F1 value. However, the F2-F1 value is almost between 1000 Hz and 1500Hz. Since the distribution of following-[ɑ]

is concentrated closely together, it can be said that there is a coarticulatory effect preceding [ɑ]. As for [i], preceding-[i] is distributed around 300 Hz and 400 Hz for F1, and 1500 Hz and 2000 Hz for F2-F1. On the other hand, following-[i] is around 500 Hz for F1, and between 1000 Hz and 1500 Hz for F2-F1. For [u], F1 for preceding-[u] is mostly below 400 Hz, and F2-F1 is between 1000 Hz and 1500 Hz. Following-[u] has the wide range of F1 values between 350 Hz to 600 Hz, but F2-F1 is concentrated at 500 Hz to 800 Hz. Thus, the three vowels can be distinguished based on the environments they appear, meaning there is a coarticulatory effect for all of the vowels.

Table 2: F1 and F2 based on the vowel position

word	vowel	occurrence	vowel position	F1-closest	F1-2ndclosest	F2-closest	F2-2ndclosest	F1Average	F2Average
aqinile	ɑ	1	preceding	493.07	506.95	1882.17	1842.89	500.01	1862.53
	i	1	following	443.3	446.72	1441.46	1462.45	445.01	1451.95
	ɑ	2	preceding	483.29	494.8	777.98	839.8	489.04	808.89
	i	2	following	459.04	456.5	1485.69	1520.05	457.77	1502.87
	ɑ	3	preceding	438.11	467.62	1978.59	1990.7	452.86	1984.64
	i	3	following	475.25	479.25	1483.77	1654.4	477.25	1569.09
aqubile	ɑ	1	preceding	724.46	682.58	1768.2	1778.19	703.52	1773.19
	u	1	following	524.82	486.23	1102.31	1136.59	505.53	1119.45
	ɑ	2	preceding	248.68	372.78	1994.85	1943.96	310.73	1969.4
	u	2	following	495.05	453.51	1194.3	1086.54	474.28	1140.42
	ɑ	3	preceding	399.93	371.81	1580.71	1468.52	385.87	1524.62
	u	3	following	431.98	419.97	967.88	902.45	425.97	935.16
iqhude	i	1	preceding	418.91	381.16	2305.29	2232.38	400.03	2268.84
	u	1	following	857.56	357.94	2669.72	849.54	607.75	1759.63
	i	2	preceding	298.2	304.35	1944.26	1817.48	301.28	1880.87
	u	2	following	502.01	480.64	1020.84	882.42	491.32	951.63
	i	3	preceding	269.59	284.74	1812.98	2017.91	277.16	1915.44
	u	3	following	383.06	409.57	971.34	947.45	396.32	959.4
fuga	u	1	preceding	321.38	333.23	1214.8	1274.33	327.3	1244.57
	ɑ	1	following	575.86	620.47	1442.61	1495.88	598.17	1469.25
	u	2	preceding	470.03	500.61	1352.78	1656.47	485.32	1504.63
	ɑ	2	following	633.18	621	1464.91	1545.6	627.09	1505.25
	u	3	preceding	336.97	370.45	2200.03	1144.29	353.71	1672.16
	ɑ	3	following	608.49	633.98	1502.97	1575.64	621.23	1539.3
iqanda	i	1	preceding	392.72	354.8	2094.56	1918.65	373.76	2006.6
	ɑ	1	following	608.77	663.06	1521.61	1453.83	635.92	1487.72
	i	2	preceding	362.44	331.65	1710.66	2411	347.04	2060.83
	ɑ	2	following	640.73	668.84	1644.96	1681.54	654.79	1663.25
	i	3	preceding	341.34	407.7	2080.36	2290.79	374.52	2185.58
	ɑ	3	following	679.62	698.73	1578.34	1600.69	689.17	1589.51
uqinile	u	1	preceding	285.24	268.66	1638.2	1570.94	276.95	1604.57
	i	1	following	418.89	475.99	1657	1730.59	447.44	1693.8
	u	2	preceding	278.11	314.37	1491.14	2017.68	296.24	1754.41
	i	2	following	335.46	407.83	1905.69	1452.07	371.65	1678.88
	u	3	preceding	277.57	320.12	1538.22	1946.05	298.84	1742.14
	i	3	following	408.14	417.45	1429.41	1528.85	412.8	1479.13
amaqanda	ɑ	1	preceding	303.05	579.45	1855.06	1915.4	441.25	1885.23
	ɑ	1	following	688.48	731.54	1495.74	1525.75	710.01	1510.75
	ɑ	2	preceding	834.54	847.36	2086.11	1995.61	840.95	2040.86
	ɑ	2	following	742.77	757.75	1541.96	1546.64	750.26	1544.3
	ɑ	3	preceding	928.42	255.25	1915.62	1690.85	591.83	1803.24
	ɑ	3	following	772.4	788.39	1607.52	1604.82	780.39	1606.17
ukuqhuba	u	1	preceding	356.74	338.7	1016.25	1608.65	347.72	1312.45
	u	1	following	642.91	549.8	1258.06	1270.51	596.36	1264.29
	u	2	preceding	342.33	314.02	1767.61	1644.62	328.17	1706.11
	u	2	following	324.52	350.79	1175.72	976.46	337.66	1076.09
	u	3	preceding	357.79	353.24	1862.67	2270.92	355.52	2066.79
	u	3	following	441.21	416.03	1224.88	1161.56	428.62	1193.22
isiqila	i	1	preceding	483	482.79	2376.73	2380.01	482.9	2378.37
	i	1	following	429.38	428.01	1748.5	1911.18	428.69	1829.84
	i	2	preceding	426.1	354.17	2198.21	2088.45	390.14	2143.33
	i	2	following	477.46	499.23	1591.96	1638.32	488.35	1615.14
	i	3	preceding	380.36	409.09	2451.23	2409.74	394.73	2430.49
	i	3	following	397.38	411.33	1778.02	2323.14	404.36	2050.58

The following Table 3 was created based on the data in Table 2. Table 3 shows the average of F1 and F2, and their difference based on different tokens.

Table 3: F1, F2 average and the difference (in Hz)

preceding	F1 average (ave)	F2 average (ave)	F2-F1
[ɑ]	524	1739.17	1215.17
[i]	371.28	2141.15	1769.87
[u]	341.08	1623.09	1282.01
following			
[ɑ]	674.11	1546.16	872.05
[i]	437.03	1652.36	1215.33
[u]	473.75	1155.47	681.72

By comparing F1 and F2 values for preceding and following vowels, features explaining the coarticulatory effect on vowels surrounding vowels can be identified.

First, in all cases, the average of F1 is higher in following vowels, and lower in preceding vowels. Since F1 is inversely proportional to vowel height, F1 is high for low vowels, and low for high vowels (Zsiga, 136). Thus, preceding vowels are higher than following vowels, which can also be said as following vowels are lower than preceding vowels.

Second, since the distance between F1 and F2 is inversely proportional to vowel backness, there is a smaller difference the more back the vowel is, and a larger difference the more front the vowel is (Zsiga, 136). All of the vowels have the same characteristic in common; F2-F1 is larger for preceding vowels, and lower for following vowels. Thus, vowels are more front for preceding vowels, and more back for following vowels. Along with this vowel backing, lip rounding causes a lower F2 (137), as it can be seen from the F2 value on the table. All of the average F2 values are lower after palatal clicks than before them. Therefore, preceding vowels are less rounded, and following vowels are more rounded.

In summary, it can be speculated from the average values of F1 and F2 that the preceding vowels are lower, more front, and less rounded, whereas the following vowels are higher, more back, and more rounded. Since there is no data of vowels which are not affected by articulatory effects, it cannot be concluded that vowels in either position are more affected. It is necessary to compare vowels without coarticulatory effects to see whether it is preceding vowels, following vowels, or both vowels that are affected by coarticulation.

The following Table 4 shows the standard deviation of each vowel both in preceding and following positions. Standard deviation shows how much values differ from the mean, so a smaller standard deviation means the values are constant, and not affected by other elements. It can be inferred that F1 value for preceding [i] and [u], and following [ɑ] and [i] are constant, while F2 value for preceding and following [u] are inconstant, and largely affected by other elements.

Table 4: F1, F2 average and standard deviation (in Hz)

preceding	F1 average (ave)	F1 standard deviation (ave)	F2 average (ave)	F2 standard deviation (ave)
[ɑ]	524	95.17	1739.17	51.99
[i]	371.28	23.17	2141.15	129.30
[u]	341.08	17.45	1623.09	278.45
following				
[ɑ]	674.11	20.25	1546.16	29.12
[i]	437.03	14.59	1652.36	126.23
[u]	473.75	61.60	1155.47	193.66

There are two words in the word list that are aspirated: iqhude [ì!ʰùdè] "a rooster", and ukuqhuba [úǩú!ʰùbà] "to drive along". They are compared with an unaspirated word aqubile [à!ùbìlè] "the one lay down in hiding", which also has [u] following the palatal click. The comparison was done using VOT, voice onset time, which is the time duration between the burst of the click and vowel periodicity, shown in Table 5.

Table 5: Comparison of VOT for aspirated and unaspirated words (in ms)

	iqhude [ì!ʰùdè]	ukuqhuba [úǩú!ʰùbà]	aqubile [à!ùbìlè]
1st token	90	96.30	33.17
2nd token	120.17	95.08	32.59
3rd token	44.97	47.32	36.14
average	85.05	79.57	33.96

As can be seen from Table 5, there is a difference in VOT between aspirated and unaspirated words; it is relatively longer for the aspirated iqhude [ì!ʰùdè] and ukuqhuba [úǩú!ʰùbà] compared to unaspirated aqubile [à!ùbìlè].

5 Discussion

5.1 *Effect on formants* From the data acquired by using Praat and vowel plot, coarticulatory effect on formants could be found, which can be attributed to the articulatory difference between the palatal click, and vowels [ɑ], [i] and [u]. The reason why the effect is found in the formants may be because of the "ease-of-articulation", as Thomas-Vilakati suggested in *Coproduction and Coarticulation in IsiZulu* (1999). The posture of the tongue, which is the tongue blade and the dorsum, is essential in producing clicks. It is expected that there is an "ease-of-articulation" effect on the adjacent vowels in order to produce sounds with ease.

6 Conclusion

In this paper, I investigated the coarticulatory effect of palatal click sounds on preceding and following vowels. I hypothesized that there is a coarticulatory effect on both preceding and following vowels. A coarticulatory effect was found in acoustic signals, and F1 and F2 values showed differences of the effect between preceding vowels and following vowels caused by height, frontness, and roundness of vowels. However, it is necessary to compare vowels with coarticulatory effect with vowels without coarticulatory effect in order to find out which of the vowels have coarticulatory effect, and this will be an area to be explored in further research.

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