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A Study of Format Dynamics in Ghanaian English Diphthongs

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ABSTRACT

This study describes acoustical characteristics of nine diphthongs in educated Ghanaian English. The diphthongs which include [eɪ], [aɪ], [ɔɪ], [aʊ], [ɛə], [ɪə], [əʊ], [ʊə] and [iu] were recorded in an /hVd/. A total of 1080 (9 diphthongs * 3 repetitions * 40 participants) utterances for diphthongs and 1080 (9 monophthongs * 3 repetitions * 40 participants) utterances for monophthongs were recorded and extracted and analyzed with PRAAT. Measurements were made for the formant frequencies, duration, amount of spectral change (Vector length VL), trajectory length, TL and the spectral rate of change, (roc.), of each of the diphthongs and corresponding monophthongs. Results indicated variations in formant trajectories for the different diphthongs and monophthongs. The dynamics of formant trajectories of Ghanaian English diphthongs displayed a relatively short steady state of the initial component, a long transition phase but no steady phase for the second component.

Introduction

Ghanaian English can be identified as a variety of English language spoken by Ghanaians living in Ghana and elsewhere. The variety is recognizable at the phonological, lexical, pragmatic and semantic levels and therefore there is a growing interest in the study of different linguistic features of this variety among Ghanaian linguistics scholars. There is still more to be done on research especially acoustic research of the Ghanaian variety of English language. As the official language of education, government, business and commerce, English language enjoys a prestigious position among the languages spoken in Ghana. The syllabuses of the educational system from primary through tertiary education in Ghana highlight the British variety of English as the approved choice however there are identified variations between English spoken by Ghanaians and that spoken by native British English speakers. It is incumbent on linguists to describe the Ghanaian variety at all levels of linguistics in order to aid the development of this variety as a legitimate one. This study is therefore a step in the right direction describing the diphthongs of the Ghanaian variety of and comparing them with component monophthongs used in transcribing the diphthongs.

This paper is a report on an investigation into spectral shapes of nine diphthongs of the Ghanaian variety of English to characterize the diphthongs using acoustic cues. Vowels of which diphthongs form a part are sound segments that occupy nucleus positions in syllables. It is important to characterize in acoustic terms the diphthongs of Ghanaian English in order to provide information on the precise characteristics of the vowels of the variety especially since this is not provided in the literature.

The diphthongs have been described variously as a type of vowel within a syllable, which moves from one vowel quality at its onset and ends with another vowel quality at its offset. This dynamic nature of the diphthong is recognized in the transcription of diphthongs which employs two vowel symbols, (Holbrook and Fairbanks 1962). This study records nine English diphthongs as spoken by educated Ghanaians and examines the dynamic nature of the formants of the diphthongs on their spectrograms.

Diphthongs are vowel sounds with a dynamic characteristic in their production. The sound quality (in terms of formant frequencies) that begins the sound is quite different from the quality that ends it. Holbrook and Fairbanks (1962) are of the view that diphthongs have a dynamic nature which is evident in the double symbols used in transcribing them. There is a movement from a more prominent vowel quality to a less prominent one (Ladefoged 2006) Holbrook et. al. suggest that more acoustic data is needed in order for a precise description of the components of the diphthongs.

This suggestion of Holbrook et. al. stems from the fact that although there have been many attempts at defining the phenomenon of diphthongs, for example Fox et. al. (2009), Mayr (2011) there are still some disagreements among scholars as to the nature of diphthongs. Catford (1977) for instance describes a diphthong as two vowels in sequence within a syllable, while Ladefoged (1982) sees the diphthong as a single vowel within a syllable.

Catford and Ladefoged seem to disagree on whether the diphthong is a single vowel sound with two vowel qualities or a sequence of vowels in the same syllable. For other scholars there are some specific vowel qualities that should be heard at the end of a diphthong. These vowels at the offset of a diphthong may have different qualities as reported by different scholars. Wong (1938) reports that the vowels /i/, /u/, and /y/ are the offset in a diphthong while Trager & Smith (1951) report that the diphthongs are sequences of vowels and semivowels so the offset for them are /j/, and /w/.

One condition that is present in all diphthongs is that there is a significant movement in vowel quality in terms of formant frequencies from one region to another on an F1/F2 plane within one syllable. Thus, whether it is considered as a sequence of vowels or one vowel with two qualities, the diphthong must be in one syllable and the movement in formants must be observable.

According to Ladefoged (1982), vowels are distinguished by three characteristic overtone pitches namely the first formant (F1), the second formant (F2), and the third formant, (F3). Vowels may be described as being monophthongs or diphthongs depending on the quality of the vowel from the beginning to the end of their production.

One condition of the diphthong that seems to be agreed on by scholars is that there must be a significant movement in vowel quality in terms of formant frequencies from one region to another on an F1/F2 plane within one syllable. Thus, whether it is considered as a sequence of vowels or one vowel with two qualities, the diphthong must be in one syllable and the movement in formants must be observable.

The movement of the second formant F2 has been seen to be the most obvious movement from the beginning to the end of the diphthong. Alexandros et. al. (2014) citing Holbrook & Fairbanks (1962) and Lehiste and Peterson (1961), state that diphthongs have been described as having formant movements from one vowel sound to another and the movement of F2 is the most obvious. The rate of transition is seen to be different from diphthong to diphthong. The movement of the second formant according to Gottfried et. al. (1993) is an important determiner of the diphthong, because the rate of transition in the second formant differs from diphthong to diphthong, (Gay 1968).

The symbols used in transcribing the diphthongs have usually suggested the onset and offset vowel qualities that constitute the diphthong. It has been argued though that in most languages there are differences between the onset and offset qualities and the symbols that have been used in the transcription of the diphthong. Holbrook & Fairbanks (1962) for instance suggest that the initial and final portions of the diphthongs hardly match those of the monophthongs that are used to transcribe the diphthongs.

On the other hand, Asu et. al. (2012), suggest that a comparison of the component target values of the diphthongs with monophthongs showed similarities and closeness to the corresponding monophthongs.

In describing the acoustic characteristic of diphthongs, correlates such as F1 / F2, duration, trajectory length, and spectral rate of change have been investigated in the literature. Studies by Fox and Jacewicz (2009), and Mayr and Davis (2011), analysed the trajectory length of sections of the diphthong as well as trajectory length of the whole diphthong. In addition, the spectral rate of change was calculated for the diphthongs. These measurements made it possible to give precise descriptions of the diphthongs in languages.

The trajectory length as noted by Fox and Jacewicz (2009) measures the formant movement in order to determine the change of formant frequency throughout the duration of the vowel. This approach proves to be useful in determining the trajectory shape of the diphthongs as Mayr and Davis (2011) corroborates its usefulness in describing the diphthongs.

These different views about the diphthong expressed by the various scholars could be an indication that the characteristics of diphthongs differ from one language to another. Therefore, evidence from different languages would give a clearer understanding of the nature of diphthongs. Results from researches on a large variety of languages are necessary to validate and support the methods used in the reported researches and the generalizations made.

This study is aimed at investigating and describing nine English diphthongs spoken in Ghana by Ghanaians. This purpose was reached by achieve three objectives: establishing the onset and offset qualities of the Ghanaian English diphthongs; describing the formant trajectories of the diphthongs in comparison with component monophthongs as seen in the symbol of each diphthong and describing the spectral rate of change in them; describing the duration of diphthongs in relation with their component monophthongs. The Ghanaian variety of English has a dearth of acoustic characterization and the current study aims at providing a systematic description of the diphthongs while comparing those characteristics with the characteristics of the monophthongs of Ghanaian English.

Some Studies on Ghanaian English Language

From Primary through the tertiary institutions in Ghana, the syllabus for teaching of English language is designed with British English as the standard. Teachers and learners of English in Ghana therefore believe that British English is the variety being used in Ghana and that is what is used in examinations. Yet there are noticeable differences when one listens to the English spoken in Ghana. This makes it obvious that there is a variety of English spoken in Ghana which is different from British English and other varieties of English. It is necessary to describe this variety in order to make it known to researchers, teachers and learners of English. Some studies on this variety of English include Grieve (1964), Sey (1973), Adjaye (1987), Gyasi (1991), Asante (1997), Dolphyne (1999), Forson (2006), and Koranteng (2006), Magnus Huber (2008), Bobda (2000), Ofori et al (2014), Ngula (2011) among others. These researchers have variously described some aspects of the English spoken in Ghana.

Forson (2006) studied argot in the Ghanaian secondary schools and Koranteng (2006) described some of the phonological features of the English spoken by educated Ghanaians. Akpanglo-Nartey (2009) also carried out an acoustic description of the vowels of Ghanaian English and realized seven monophthogal vowels used in representing the twelve English vowels. Ngula (2011) investigated Ghanaian English pronunciation which he said is based on the spelling of English words. Akpanglo-Nartey (2009) studied the vowels of Ghanaian English for her PhD degree and found that the speakers of Ghanaian English studied produced the monophthongs [e] and [o] in place of the British English diphthongs [eɩ] and [ou]. She reported that Ghanaian English speakers produced seven monophthongs: [i], [e], [ɛ], [a], [ɔ], [o], [u] (with slight local variations within GhE vowels depending on the indigenous linguistic background of the speaker) which quite tally with the vowel inventory of most Ghanaian languages. The diphthongs identified in the study were: [ai], [au], [iɛ], [ɔi], [uɔ] though these were not analyzed in the study. Akpanglo-Nartey (2012) reported on effects of gender differences on vowel quality in Ghanaian English and concluded that the vowels of female speakers of Ghanaian English studied were more fronted and that females tended to produce longer vowels than males.

In most of these studies, except for the Akpanglo-Nartey's (2009; 2012) studies which used measurable acoustic values in describing the vowels, the researchers simply listened to the variety and then described what they heard using an impressionistic approach to the study. Both studies carried out by Akpanglo-Nartey focused only on the monophthongs of the variety without considering the diphthongs yet there are diphthongs that ought to be described as well as the monophthongs.

Thus far, there is no systematic phonetic description of the diphthongs of Ghanaian English. The purpose of this study therefore is to bridge the gap by providing empirical data to characterize diphthongs in Ghanaian English. This is in line with the convictions of Ladefoged (1964) and Nartey (1982), among others, that any systematic differences between any two languages or dialects of the same language must be described for the benefit of grammarians. It is the duty of linguistic phoneticians, to systematically describe all speech sounds used in natural languages. According to Ladefoged (1978) in order to have a good description of a language there must be a description of the phonological patterns in the language as well as characterize the sounds in terms of some absolute phonetic standards. The current study therefore sets out to achieve the following objectives:

- find out how similar or different the formant characteristics at the Target one and Target two of the diphthongs are to monophthong symbols with which they are transcribed;
- identify the trajectory paths of the diphthongs of Ghanaian English and compare the trajectory lengths between different sections of the diphthong;
- determine the differences or similarities in length between the diphthongs and monophthongs to find out if the diphthong could be argued to be a combination of two monophthongs;
- find out how the diphthong could be characterized with the spectral rate of change of different sections;
- determine differences or similarities in the trajectory lengths of diphthongs and those of monophthongs.

In order to find acoustic correlates of the Ghanaian variety of English, this study is guided by the following research questions:

- How do the onset and offset of the Ghanaian English diphthongs relate in terms of vowel quality (F1 and F2ˈ), with the monophthong symbols with which diphthongs are transcribed?
- What are the trajectory paths of the Ghanaian English diphthongs and which sections of the diphthong have the largest values for trajectory length?
- How similar or different are the durations of diphthongs and monophthongs?
- At which points in their entire duration do diphthongs show the most change in spectral shape?
- How do the diphthongs differ from monophthongs in terms of their trajectory length?

The results of this current study will provide a set of comprehensive reference data on the acoustic characteristics of the diphthongs of Ghanaian English spoken by educated Ghanaians between ages 18 and 30 years old.

Methods

Participants

Twenty Ghanaian students (made up of ten males and ten females) and ten Ghanaian lecturers (made up of five males and five females) from the University of Education, Winneba participated in the study. The ages of the participants range between 20 years and 40 years. All the participants had been in Ghana almost all their lives and their education had all been in Ghana. All the participants hailed from the southern parts of Ghana specifically from Greater Accra, Eastern, Ashanti, Volta and Central Regions of Ghana.

Speech Materials

Vowel data of nine English diphthongs as well as corresponding monophthongs were recorded in an environment of ‘hVd’ (Mayr 2011) as shown in Table 1 below. The ‘hVd’ environment has been used in most acoustic studies of vowels. This is because the initial [h] and the final [d] do not have much acoustic influence on the vowel. The phonetic environment ‘bVd’ was avoided because that environment results in too many ‘nonse’ words in the study. Also to minimize transitional effects at the onset of the vowels nasals, laterals, alveolar sound, and velars were not included as environments for the vowels in the study.

The target words were said in a sentence frame: ‘say…. again’. Participants read the sentences in three repetitions in a randomized order at normal speaking rate.

Table 1. Monophthongs and Diphthongs in test words

Diphthongs	**Target words**	**Monophthongs**	**Target words**
[ei]	Hayed	[i]	heed
[əʊ]	Hoed	[ɪ]	hid
[ai]	Hide	[ɛ]	head
[aʊ]	how’d	[æ]	had

[ɔi]	Hoyed	[ɑ]	hard
[iə]	Here	[ɔ]	hoard
[ɪu]	Hued	[ɒ]	hod
[ɛə]	Haired	[ʊ]	hood
[ʊə]	Toured	[u]	Who'd

Recording

In order to get the data for analysis, care was taken to record the sounds in a conducive environment where participants were sure of their productions. Participants were given the prior assurance that the exercise was for research purposes only. Participants were given the opportunity to familiarize themselves with the target words by reading through them to get used to them before recordings began. The recordings were done in a sound proof speech and hearing laboratory using an external microphone connected to a laptop recording directly through PRAAT speech analyzer with 20-kHz sampling rate and 16-bit resolution. The word list, used in major phonetic studies of English vowels (for instance, Peterson & Barney, 1952 (American English); Wells, 1962 (British English); and Cox, 2002 (Australian English) was used in this study.

Analysis

The target sounds were separated from the initial and final consonants of the test words by observing the onset of vibration that followed the initial consonant and the reduction of the amplitude in the waveform of the final consonant. The first pulse of vibration and the last pulse of vibration in the vowels were enveloped and selected in the waveform and the spectrogram. This segmentation was done manually on the waveform and spectrogram and saved for further analysis.

The recorded data was subjected to spectrographic analysis and frequency values for the first, second and third formants (F1, F2, F3) were obtained from five points: 20%, 35%, 50%, 65% and 80%, (Fox and Jacewicz (2009) along each vowel recorded. With the help of the formant movement, the vowels were again segmented into onset, target one, transition, target two and offset, (Yang 2015) so as to examine the initial portions of the diphthong.

Values for the durations of the vowels were also obtained from the spectrograms. The duration of different parts of the diphthongs were ascertained for comparison purposes in line with Gay (1968), Lindau (1984) and Lindau et. al (1990). These helped to define the acoustic properties of the diphthong sounds of Ghanaian English. A total of 1620 (9 diphthongs * 3 repetitions * 60 participants) utterances for diphthong and 1620 (9 monophthongs * 3 repetitions * 60 participants) for monophthong segments were analyzed in this study.

Based on Scarborough (2005) the beginning and ending position of each vowel was determined by enveloping the whole duration of the segment from the speech spectrogram on Praat. The voicing pulse marks on the sound waveform as well as the changes of amplitudes in the waveform and the intensity shape in the spectrogram served as clues in determining the beginning and end of the vowels. The onset of the vowel was taken after the frication noise at the onset of vibration in the vowel while the end of vowel was determined from the offset of higher-frequency components.

Praat Settings

For the spectrogram setting the window length used was 0.005s with the Gaussian window shape and the view range up to 5000Hz for both the males and females. Fourier analysis method is used in spectrogram analysis settings. In formant settings, a maximum formant of 5500Hz for five formants with window length of 0.025s was used for the females and 5000Hz was used as maximum for the males. Pitch range used were 100Hz to 500Hz for females and 75 to 400Hz for males.

Monophthongs

So as to compare component parts of the diphthongs with monophthong symbols used in the transcription of diphthongs, the monophthongs of the participants were also analyzed although there had already been an acoustic description of the monophthongs of Ghanaian English (Akpanglo-Nartey 2009). The duration and first three frequency values (F1, F2 and F3) were calculated for each monophthong vowel from the spectrogram and a formant chart plotted using average F1 and F2' values. Also, Trajectory Length (TL), Vector Length (VL) and Spectral rate of change in the various sections of the vowel were calculated.

Diphthongs

As was analyzed for the monophthongs, the duration and first three formants of the diphthongs were determined from the spectrogram. The measurements for the formants were taken at five points in the course of the vowel: the 20, 35, 50, 65 and 80 percent points were calculated and targeted for the measurements. Again the first and second steady states (Target 1 and Target 2) as well as transitions from Target 1 to Target 2 of the diphthongs were ascertained and their durations and formant frequency values determined. Trajectory Length (TL), Vector Length (VL) and Spectral rate of change in the various sections of the vowel were also calculated as with the monophthongs.

Formant Frequencies

The F1, F2 and F3 values were automatically tracked on the spectrogram using the formant history tracks which estimates the locations of the formants. The values were queried at the 20, 35, 50, 65 and 80 percent points on the spectrograms and formant values were recorded. This was also done for the Target 1, Target 2 and the transition between targets 1 and 2.

Vowel Duration

Using waveform display as well as spectrogram display of the speech signal, the onset and offset of the vowels were located by hand in order to determine the duration of the vowel. The onset of the vowel was marked at the beginning of periodicity, (Fox and Jacewitcz 2009), at the point with higher amplitudes and the offset was determined at the point where the amplitude reduced drastically. This is because during the closing of the voiced consonant the waveform shows only slow variations, (Olive et al., 1993) yielding lower amplitudes. The duration of the vowel is then taken from the spectrogram in milliseconds.

Vector length (VL)

The amount of formant change (or Formant movement) was measured by calculating the vector length between the 20% point and 80% point in the vowel plane. This was done in consideration of Hillenbrand et al. (1995) and Ferguson and Kewley-Port (2002), studies which are of the view that the amount of change in the formants during the length of a vowel especially between the 20% point and 80% point is proportional to the length of the vector. Thus diphthongs will have longer vectors than monophthongs if the amount of formant movement is greater. According to Fox and Jacewicz (2009), the measure of vector length is used to measure diphthongs in which direction of formant movement change over time. The vector length, VL, is measured between the 20% and 80% points of the vowel duration by calculating the square root of the square of formant one at the 20% point, ($F1_i$) minus Formant one at the 80% point ($F1_v$), plus the square of formant two at 20% point minus formant two at the 80% point, Fox and Jacewicz (2009):

$$VL = \sqrt{(F1_i - F1_v)^2 + (F2_i - F2_v)^2}.$$

Trajectory Length (TL)

Trajectory length TL is a measure of spectral change which marks formant movement in the F1/F2 vowel space across equidistant sections of the vowel. This measure assesses the formant frequency change throughout the vowel duration. With Fox & Jacewicz's (2009) study in view, the trajectory length TL, was calculated for each diphthong at four sections: 20%–35%, 35%–50%, 50%–65% and 65%–80% and then a total was calculated from the sum of TL of all the sections. The TL of each section was calculated on the basis of the following formula, where VSLn constitutes the length of one vowel section:

$$VSLn = \sqrt{(F1n - F1n\text{-}1)^2 + (F2n - F2n\text{+}1)^2}$$

Spectral Rate of Change (roc)

Spectral rate of change calculates the amount of formant frequency change across the vowels duration, (Fox and Jacewitcz 2009). Differences in the vowel dynamics were examined by calculating the spectral rate of change over the 60% portion of the vowel and also rate of change in each vowel section. Spectral rate of change was calculated separately for each section (VSLrocn) on the basis of the following formula:

$$VSL\ rocn = VSLn / (0.15 \times \text{vowel duration})$$

Spectral rate of change over the 60% portion was calculated with the formula:

$$TL\ roc = TL / (0.60 \times \text{vowel duration})$$

Results

This section presents findings on vowel durations discussing differences between monophthong and diphthong in terms of their durations. The section also presents findings on the formant trajectories of the diphthongs indicating those that are near monophthongs looking at their onset and offset positions on the vowel space. The vector length is presented in this section to indicate how formants changed from the onset to the offset of the vowel. The section again discusses trajectory length of the diphthongs to show the section of the vowels that show the most movement in their formant frequencies. Findings of spectral rate of change of the vowels are also presented in this section.

Vowel Duration for Monophthongs and Diphthongs

To show clearly the difference in length between monophthongs and diphthongs, the duration of the vowels were measured and comparisons between and within vowels were made. Values for the duration of the vowels are shown in Table 2 below.

Among the monophthongs, the shortest vowel, hood [ʊ] measured 148ms and the longest, hard [ɑ] measured 302ms. The longest diphthong was 321ms and the shortest was 265ms. The mean of the duration of monophthongs came to 253ms while that of the diphthongs came to 292ms, a difference of 39ms.

The data showed that the tense vowel [i] was about 31ms longer than its lax counterpart, [ɪ] and the tense vowel [ɑ] was longer than [æ] by 33ms. The monophthong [ɒ] on the other hand was longer than its tense counterpart [ɔ] by 16ms. The tense vowel [u] was also longer than its lax counterpart [ʊ] by 120ms, representing the most difference in duration between tense and lax vowels. The current results in conformity with Akpanglo-Nartey (2012), showed tense monophthongs slightly being longer than lax monophthongs in Ghanaian English.

The data supports the study of Akpanglo-Nartey (2012) that monophthong pairs in each vowel zone for instance HEED [i] and HID [ɪ], WHO'D [u] and HOOD [ʊ], HARD [ɑ] and HAD [æ], HOD [ɒ] and HOARD [ɔ] show some differences in their duration measurements. This was confirmed in the current study as the measurement values in Table 2 and Figure 1 show.

Table 2: Averaged durations of monophthongs and diphthongs in milliseconds

Vowel	Duration	Vowel	Duration
heed [i]	258	hide [aɪ]	271
hid [ɪ]	225	hoyed [ɔɪ]	282
hayed [eɪ]	274	how'd [aʊ]	267
head [ɛ]	263	hued [ɪu]	281
had [æ]	265	haired [ɛə]	320
hard [ɑ]	300	toured [ʊə]	324
hod [ɒ]	273	sure [ʊə*]	269
hoard [ɔ]	255	here'd [ɪə]	321
hoed [əʊ]	266		
hood [ʊ]	148		
who'd [u]	266		

The mean durations of monophthongs and diphthongs for speakers of Ghanaian English as shown in Table 2 and Figure 1 indicated that monophthongs and their corresponding diphthongs were differentiated by differences in their lengths. All the monophthongs were produced shorter than their corresponding diphthongs except with the [æ] / [aɪ] and [æ] / [aʊ] pairs in which the diphthong was not largely longer than the monophthong. For this group of speakers the shortest diphthong was found in 'HOW' [aʊ] and it measured 267ms. The average length of the monophthongs put together was 253ms and the diphthongs was 291ms. Statistically the differences between the lengths of diphthongs and monophthongs were significant (p< .001two-tail).

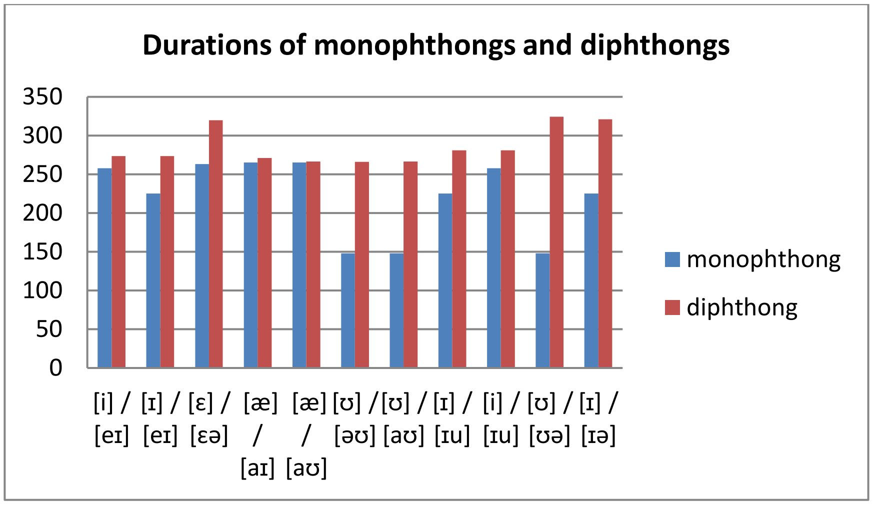


Figure 1. Duration of diphthongs and monophthongs.

The figure represents the duration of diphthongs and their composit monophthongs eg. [i] / [eɪ]; [ɪ] / [eɪ]; [ɛ] / [ɛə].

Despite the significant difference in the durations of monophthongs and diphthongs, the composite duration of a diphthong could not be said to be a sum of the duration of two monophthongs that constituted the diphthong. The diphthong [ɔi] for instance measured 283ms but [ɔ] measured 258ms while [i] measured 261ms obviously the sum of the two vowels exceeded the duration of [ɔi].

As shown in Figure 2, the monophthong in 'HOARD' [ɔ] appeared longer than 'HOOD' and 'HID' but shorter than other monophthongs such as those of 'HOD' [ɒ], 'HAD' [æ] and 'HEAD' [ɛ]. 'HOARD' [ɔ] measured only slightly shorter in its duration than some of the diphthongs such as those in 'HOW' [aʊ], and 'SURE' [ʊə]. The monophthong of 'WHO'D' [u] was produced almost as long as 'HIDE' [aɪ] and the monophthong of HARD [ɑ] was produced longer than HIDE [aɪ], HOYED [ɔɪ], HOW'D [aʊ], HUE'D [ɪu] and SURE [ʊə]. Only three diphthongs went beyond 300ms in their lengths and these were the diphthongs in 'TOUR' [ʊə], 'HERE' [ɪə] and 'HAIR' [ɛə] while the other diphthongs were between 260 and 280 milliseconds. Looking at the durations of monophthongs individually and comparing them with the durations of diphthongs may give the impression that the durations of some monophthongs are within the mean duration of the diphthongs.

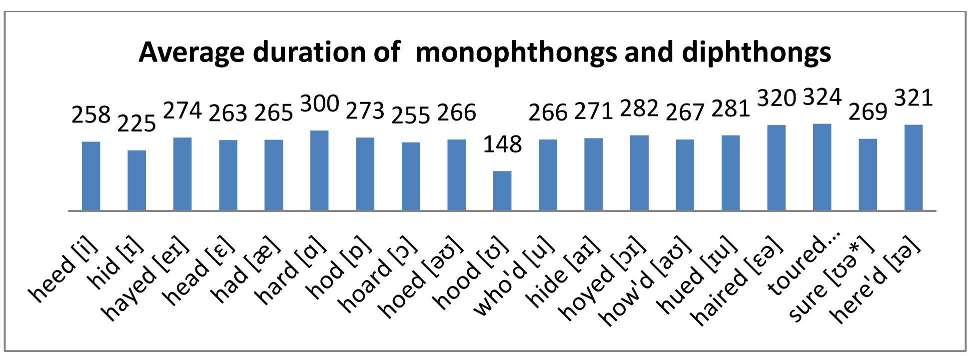
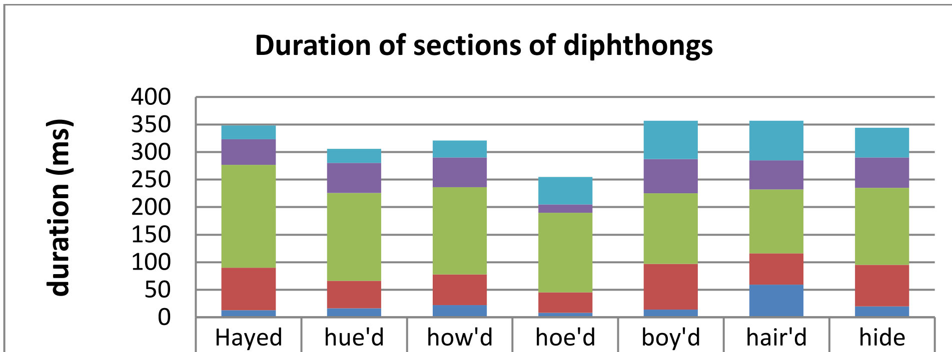


Figure 2. Average duration of diphthongs and monophthongs.

The onset, target one, transition, target two and offset durations as shown in Figure 3 indicated that all the diphthongs except [ɛə] had relatively very short onset but longer offset especially for the 'HOE'D', 'BOY'D', 'HAIR'D' and 'HIDE' vowels. The transition period was the longest section in the diphthong trajectory. This indicates that there was much more variability in the transition period and that the steady states (Target 1 and Target 2) were really very short compared to the transition periods. Thus there was much variability in the various parts of the diphthongs. This supports the view that the diphthongs are better regarded as vowels with dynamics in their qualities rather than a combination of two monophthongs, (Holbrook and Fairbanks 1962).

Target one was shortest for the HOE'D vowel and longest for the 'HOY'D' vowel. The analysis showed that the vowels in 'HAY'D' and HOE'D had relatively short target two (46ms and 15ms respectively). This is an indication of the monophthongal nature of the two vowel sounds in this variety of English. For most of these sounds target one and target two are not very different in length.



	Hayed	hue'd	how'd	hoe'd	boy'd	hair'd	hide
offset	25	26	31	50	70	72	54
Target 2	46	54	54	15	62	53	55
Transition	187	160	158	145	128	116	140
Target 1	77	50	56	37	83	57	75
onset	13	16	22	8	14	59	20

Figure 3. Durations of diphthong onsets, targets, transitions and offsets.

The divisions of the bars are such that from the top the first cell represents the offset duration, followed by the target two duration then the transition, target one and then the onset durations.

Formant Movements

The movement of F1 and F2 on the vowel space is discussed in terms of changes in the formants of both monophthongs and diphthongs from the 20%, 35%, 50%, 65% and 80% points of their durations. Although the monophthongs were studied in the earlier acoustic study of Ghanaian English vowels by Akpanglo-Nartey (2012), they were included in this study in order to be able to compare the speaker's monophthongs and their diphthongs. This approach helped in describing the onset and offset of the diphthongs.

Formant Movement In Monophthongs

The location of monophthongs in the vowel spaces for both the male and female speakers and the amount of movement displayed in their formants were very characteristic of Monophthongs. This was also true for the movement of formants in the vowels in HAY'D [ei] and HOE'D [əʊ] especially in the F2 dimension. In Figure 4 ellipses round the vowels were small and showed very little movement in the F1 and F2 dimensions for these vowels. The vowels in 'HAY' [ei] and 'HOE' [əʊ] showed slightly more movement in the F1 dimension but none in the F2 dimension. This relatively small movement in the F1 dimension was also observed in other monophthongs such as [i], [ʊ], [ɔ] [u] and [ɒ].

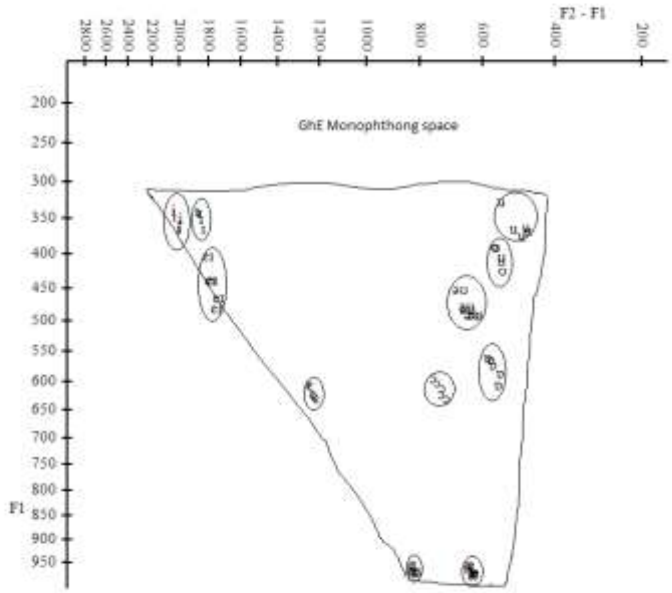


Figure 4. Monophthong vowel space of Ghanaian English vowels.

The results of monophthong placement in the vowel space as shown in Figure 4 is a confirmation of Akpanglo-Nartey's (2012) description of the monophthongs of Ghanaian English. There is evidence of conflation of vowels in the different vowel zones in the vowel space. Both males and females though showed a lower and less back [ʊ] than [u] and a more fronted [ɔ] than [ɒ] on their vowel spaces.

Formant movement in Diphthongs

The English diphthongs investigated in the study include [aɪ] 'HIDE' [ɔɪ] 'HOY', [aʊ] 'HOW', [ɪu] 'HUE', [ɛə] 'HAIR', [ʊə] 'TOUR', [ʊə] 'SURE', [eɪ] 'HAY', [əʊ] 'HOE' and [ɪə] 'HERE'. The trajectories of F1 and F2 of the diphthongs through the onset, target one, transition, target two and offset as well as the trajectory in the five sections of the diphthongs are discussed in this section.

F1 and F2 Movement in diphthongs

The F1 movement through the durations of the diphthongs showed that there were steady states in the Target one and Target two locations for most of them however the steady states were rather short for most of the diphthongs. This means that it is legitimate to posit two steady states for some of the diphthongs but only one for the others. For instance, HAIR'D showed steady F1 in target one but F1 was not steady in the position for target two indicating only one steady state. The HUE'D vowel showed a very short steady state in the F1 of target one but a longer state in the target two which indicated a one steady state vowel. HERE'D showed a relatively steady F1 in target one and target two thus showing a two steady state diphthong. The F1 for HOE'D was not steady in target one and but steady target two.

Therefore, on the basis of the F1, only the HERE'D vowel showed two steady states and could be classified as a diphthong. The F2 on the other hand was found to be steadier in the target one and target two of almost all the diphthongs than the F1.

In determining the steady states however, both F1 and F2 of the diphthongs were used as the clue to demarcate the target one, transition and target two. The targets were therefore marked at portions where there was relative steadiness for both the F1 and the F2. Trajectory lengths for these steady phases were calculated for each of the sections in order to determine how steady the formants were in those sections. Results indicated that F1 and F2 together could not determine the steady states as they were not very steady for all the diphthongs except in the vowel [ʊə] 'TOUR'D', where F1 and F2 were both relatively steady in target one.

Two steady states in the diphthongs investigated were really difficult to come by. Some of them showed a relative steady target one but not target two while others had a relatively steady target two but not target one. HERE’D, HUE’D, HOY’D and HAY’D vowels showed relatively steady and longer target one but not target two.

HAY’D and TOUR’D showed the biggest variability in target two which is an indication that a steady target two was nonexistent. The diphthong HERE’D had very minimal variation in the target one and target two, in other words there was a steady target one and target two for this vowel. In all the diphthongs, ‘HERE’D is the one with the steadiest target two.

Table 3. Trajectory length of Onsets, targets, and offsets

Vowel	onset	target1	Transition	Target 2	Offset
Hayed	183.1	96.2	138.7	174.3	140.2
hue'd	279.4	34.0	814.8	67.0	75.1
how'd	46.7	106.6	271.9	75.6	68.0
hoe'd	215.9	145.3	226.9	35.0	448.1
boy'd	113.5	70.0	127.6	34.0	349.2
hair'd	285.3	180.6	360.9	0.0	146.2
Hide	250.0	180.3	209.1	50.0	0.0
Toured	9.6	3.7	365.7	212.6	2.0
Sured	4.2	2.4	189.2	32.0	4.1
here'd	8.2	1.9	154.9	4.3	3.6

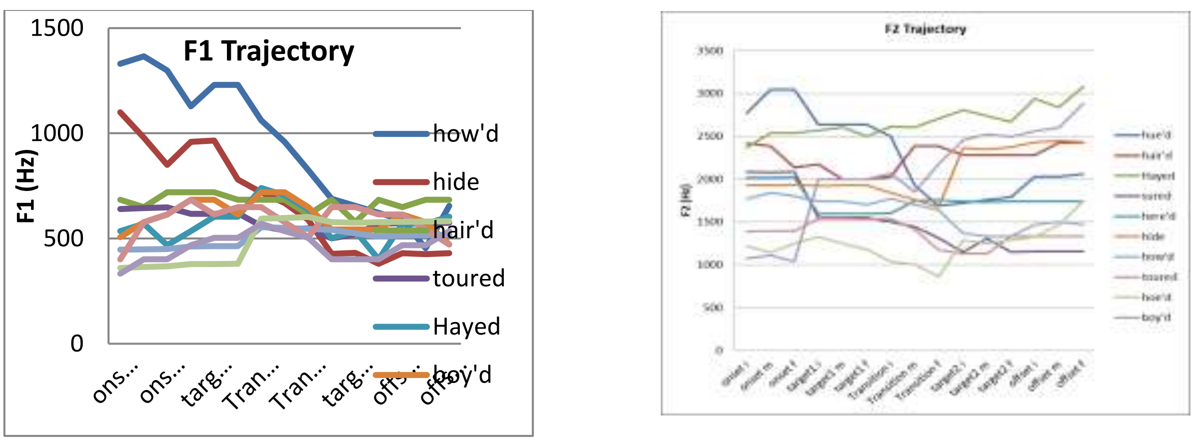


Figure 5. F1 and F2 trajectory of diphthongs.

From the top line to the bottom line in the figure, the trajectories represent F1 for HOW’D, HIDE [aɪ], HAIR’D [ɛə], TOUR’D, HAY’D [eɪ], BOY’D [ɔɪ], SURE’D, HOE’D [əʊ], HERE’D and HUE’D [ɪu] respectively. For the F2 trajectory, the top first line represents F2 trajectory for HUE’D and this is followed by that for HAIR’D, HAY’D, SURE’D, HERE’D, HIDE, HOW’D, HOE’D and BOY’D respectively. The lines are arranged according to the onset positions in the line graph.

The next diphthong with a relatively steady target two was ‘SURE’D, followed by BOY’D, HOE’D, HIDE, HUE’D, HOW’D, HAY’D, and then ‘TOUR’D. Diphthong ‘HAIR’D showed an unsteady target one but a very steady target two as Figure 5 shows. In fact the TL value shown in Table 3 indicated no change between the initial and final value of the F1 and F2 values of target two and that yielded a zero TL for that section. As far as steady states are concerned therefore, each of the diphthongs had either a steady target one or target two. A very steady target one and target two in one single diphthong was not achieved in the data.

Ghanaian English closing diphthongs [aɪ], [eɪ] and [ɔɪ]

The front rising diphthongs identified in the data as shown in Figure 6 presented a movement from one vowel zone to another but these vowel zones did not tally with the actual vowel positions for the monophthongs and diphthongs suggested by the symbols used for their transcription. This movement was very obvious especially where the vowel zones were far apart like in [ɔɪ] and [aɪ].

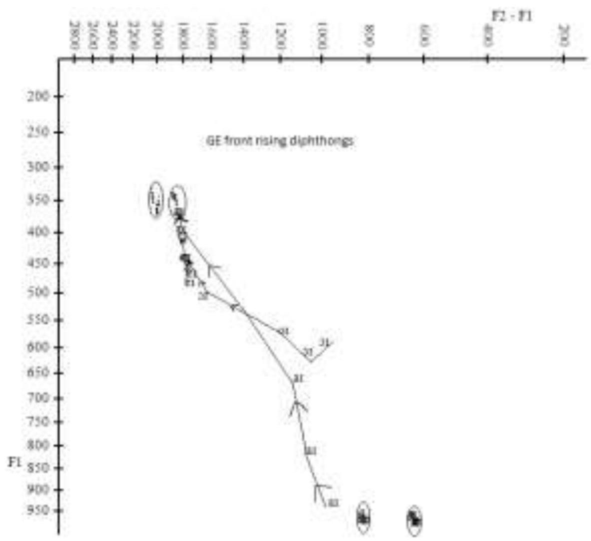


Figure 6. Front rising diphthongs in Ghanaian English

Except for [eɪ], the diphthongs did not start from the positions of the vowel symbols for transcription. For instance, the initial vowel quality for [aɪ] started at a position more front and higher than the position for [a] as indicated in Figure 6. The diphthong [ɔɪ] as well did not start as back as the monophthong [ɔ], the start position being as central as [ə].

As far as the final vowel quality in these diphthongs are concerned, the diphthongs [ɔɪ] and [eɪ] presented an 'undershoot' (Lindblom 1990) as shown in Figure 6. The final vowel quality in the two diphthongs did not get to the vowel position for [ɪ] and [ɔɪ] ended in the position for [e]. The trajectory for the diphthong [eɪ] rose slightly above [e] and ended below the position for [ɪ]. The trajectory of the diphthong [aɪ] on the other hand ended at the position for [ɪ] which incidentally is the same height as [i] for these participants. The diphthongs symbols could therefore be represented as [ai], [əe] and [ee] going by their start and end positions, showing the monophthongal nature of [eɪ].

Ghanaian English back closing diphthongs [ɪu], [aʊ] and [əʊ]

There were back closing diphthongs as is shown in Figure 7, in which the second vowel quality did not quite get to the region for high back vowels. The study recorded the diphthong [ɪu] produced in word HUE'D. This diphthong trajectory was initiated at a position around [e] and ended at a position more front than the monophthong [ʊ] position in the vowel space showing a diphthong like [eʊ]. Also [aʊ] started above the low center region for [a] and ended at the region for [ə] in the vowel space. Thus rather than ending near [ʊ] the trajectory ended around the central vowel [ə] making the diphthong more like [aə]. There is also the diphthong of HOE'D [əʊ] which was produced more as a monophthong than a diphthong. This vowel trajectory started at a position in the vicinity of [o] and ended in that same vicinity.

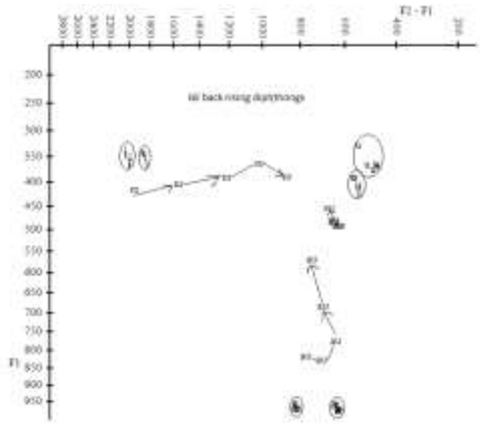


Figure 7. Ghanaian English back rising diphthongs.

Ghanaian English centering diphthongs [ɛə], [ʊə] and [ɪə]

Out of three centering diphthongs investigated in the study, two of them: HAIR'D [ɛə] and TOUR'D [ʊə] were produced as monophthongs as evidenced in Figure 8 by the relatively short movement in their trajectories from the start to the end. The third diphthong HERE'D [ɪə] had a characteristic closer to [ɪɛ]. In effect the study could not find any real centering diphthong except in the production of [aʊ] which though not a centering diphthong in British English had a second vowel quality of [ə]. The diphthong in SURE'D [ʊə] (indicated with ʊiə* on the vowel space in Figure 8) was produced differently from the diphthong in TOUR'D. As Figure 8 shows, the trajectory of this vowel started at a point below the onset for [eɪ] and ended around the position for [ɔ] suggesting a diphthong like [eɔ].

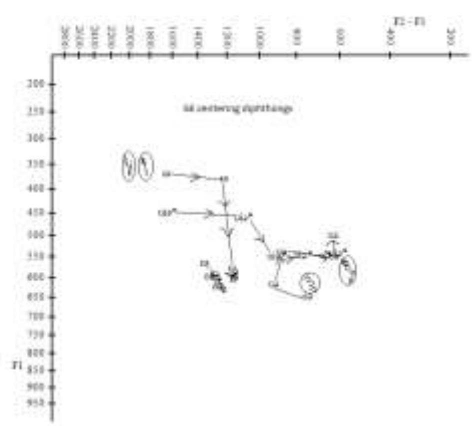


Figure 8. Ghanaian English centring diphthongs

The diphthong for 'TOUR' [ʊə] shows a movement with an onset from the zone around [ɔ] and an offset slightly above the [ɔ] zone but not quite in the zone for [o] on the vowel space. Thus, that sound is produce with an [ɔ] monophthongal quality.

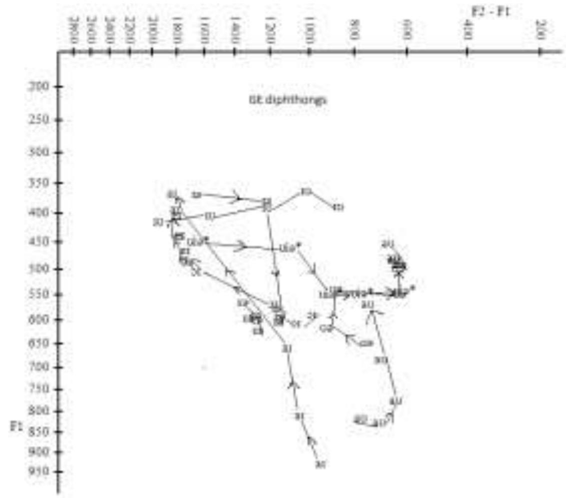


Figure 9. Ghanaian English Diphthongs

Similarly, trajectory for the diphthong in ‘HOE’ [əʊ] shows slight movement from onset to offset though the movement is minimal as compared to the movement in ‘hide’. The vowel qualities at the onset and offset of the ‘HOE’ [əʊ] vowel did not change much. The onset was found in the zone of [o] and the offset is also found around the same zone of [o] in the vowel space. This is an indication that the ‘HOE’ [əʊ] vowel was produced more like a monophthong [o] than a diphthong as noted in Koranteng’s (2006) and Akpanglo-Nartey’s (2009) studies. The vowel for ‘HAY’ [eɪ] in the front space is produced in the same manner as the vowel for ‘hoe’ in the back space. It had an onset found in the zone for [e] and an offset also in the [e] zone of the vowel space. This suggests that the vowel in ‘hay’ is more of a monophthong than a diphthong.

VECTOR LENGTH

The vector length VL was measured to identify the dynamics of the formants from the onset to the offset, (Fox & Jacewicz, 2009). The results of these measurements showed that among the monophthongs [æ] had the shortest VL of 14ms while [i] had the longest VL of 49ms. This is shown in Table 4 and also Figure 10. The formants in [æ] had less movement than the other monophthongs. The vowel [eɪ] with a VL of 63ms showed more change in the formant movement than the monophthongs though the difference in VL is only 14ms. Therefore, this vowel was slightly more diphthongal than the monophthongs examined. The ‘HOED’ vowel [əʊ] on the other hand was shown to be less diphthongal showing less movement in the formants as indicated by its VL of 31ms.

The vowels [ɔ], [ʊ] and [u] showed longer VL than the VL of [əʊ]. Therefore, the vowel in ‘HOED’ seemed to be pronounced in a less diphthongal manner than the vowel in ‘HAYED’. The values obtained showed some amount of spectral change for all the monophthongs though but in comparison with the values obtained for the diphthongs, those spectral changes were minimal.

Table 4. Averaged Vector length of monophthongs and diphthongs

Test word	Monophthong	Vector length (ms)	Test word	Diphthong	Vector length (ms)
heed	[i]	49	hide	[ai]	659
hid	[ɪ]	26	hoyed	[ɔi]	653
hayed	[eɪ]	63	how’d	[aʊ]	372

head	[ɛ]	20	hued	[ɪu]	980
had	[æ]	14	haired	[ɛə]	38
hard	[ɑ]	24	toured	[ʊə]	306
hod	[ɒ]	18	sure	[ʊə]	945
hoard	[ɔ]	42	here'd	[iə]	347
hoed	[əʊ]	31			
hood	[ʊ]	43			
Who'd	[u]	36			

The VL measurements as shown in Figure 10 indicated also that the 'HAIRED' diphthong had the least amount of spectral change indicated in the relatively small vector length of 38ms. This was an indication that the vowel [ɛə] was pronounced more like a monophthong as the vector length indicated. The 'SURE' vowel [ʊə] showed the most spectral change with a VL of 945ms. The amounts of spectral change in the vowels 'HUED', 'HIDE', 'HOYED', 'HOW'D' and 'HERE'D' follow in that order. An ANOVA results showed significant differences between the VL of these diphthongs and the VL of the 'HAYED', HOE'D and 'HAIRED' vowels.

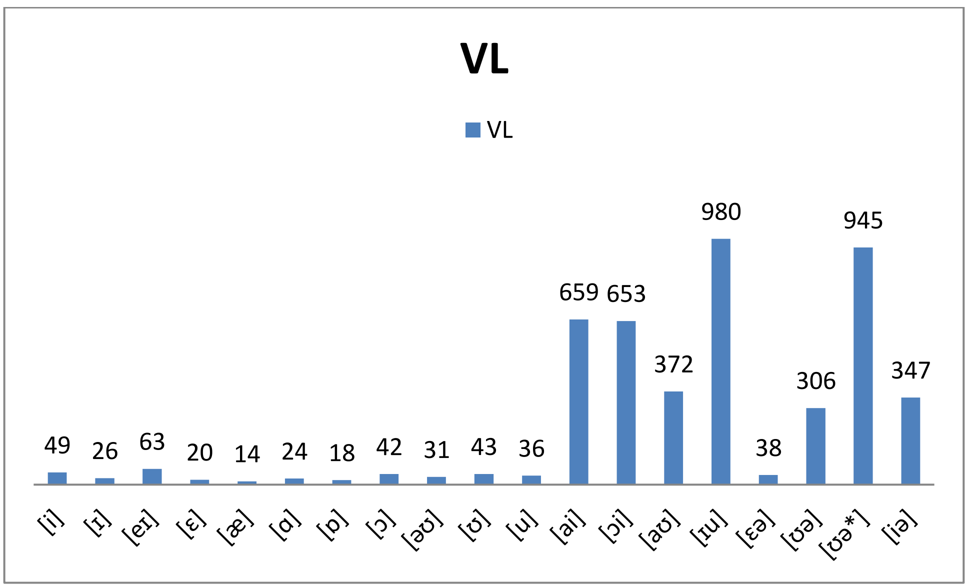


Figure 10. Vector Length (in Hz) of Monophthongs and diphthongs

TRAJECTORY LENGTH

Measuring the trajectory length of four sections of the vowels gave an indication of sections where there were more change and sections with less change in the formant frequencies. The results of the total TL of the four sections gave a more vivid indication of the change in the formant frequencies over time. The TL values as shown in Table 5 above indicated that the 'HAD' vowel had the least change with a TL value of 53ms.

The TL measurements showed larger values than the VL measurements which goes to support the claim by Fox and Jacewitcz (2009) that the TL values measured for TL are larger than the values for VL giving a more detailed estimate of the formant change. The diphthongs showed significantly larger TL values than the monophthongs. This indicated more change in their formants in the duration of the vowel than there was in the monophthongs. Figure 11 is a graphical representation of the TL of the monophthongs and diphthongs.

Table 5. Averaged Trajectory length (in Hz) of monophthongs and diphthongs

Test word	vowel	TL	1	2	3	4
heed	[i]	125.2	7.2	33.7	43.7	40.55
hid	[ɪ]	87.75	29.7	15.35	33.65	9.05
hayed	[eɪ]	129.3	28.95	43.85	11.4	45.05
head	[ɛ]	68.4	9.35	26.25	16.3	16.55
had	[æ]	53.8	19.1	9.65	7.65	17.35
hard	[ɑ]	84.55	23	20.15	20.05	21.35
hod	[ɒ]	136.7	49.3	46.05	28.75	12.55
hoard	[ɔ]	67.35	24.2	20.75	12.75	9.65
hoed	[əʊ]	85.3	3.75	23.75	18.35	39.4
hood	[ʊ]	56.75	17.2	10.3	22.8	6.45
Who'd	[u]	138.3	10.15	38.15	37.15	52.8
hide	[ai]	856.1	121.95	177.1	513.65	43.3
hoyed	[ɔi]	670.9	98.45	93.65	418.2	60.55
how'd	[aʊ]	426.05	65.15	125.3	100.9	134.65
hued	[ɪu]	1310.15	421.55	357.1	346.2	185.4
haired	[ɛə]	172	19.65	11.6	56.65	21.8
toured	[ʊə]	598.25	82.65	73.6	125.3	27.65
sure	[ʊə*]	981.85	269.05	91.15	131.85	14.7
here'd	[iə]	727.6	216.45	135.85	4.85	14.15

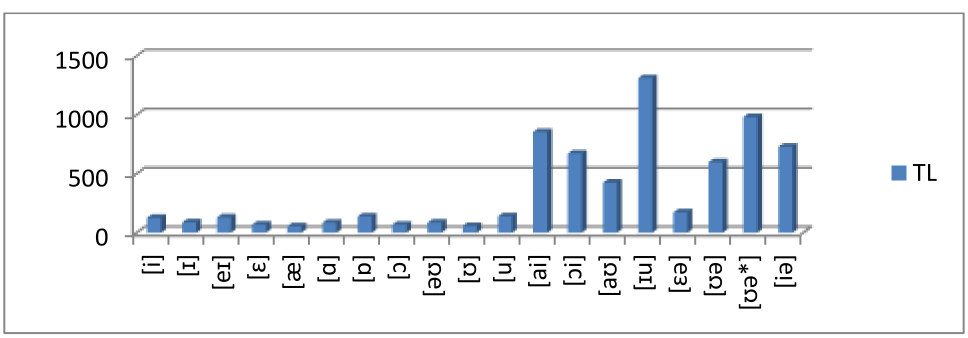


Figure 11. Average Trajectory Length (in Hz) of monophthong and diphthong vowels

Spectral Rate of change (roc)

The spectral rate of change measured in milliseconds, showed yet some more details which were not shown in the TL measurements. As shown in Figure 12 values for the spectral rate of change at 60% of the duration of vowels showed that the 'HOOD' vowel had larger spectral roc than the 'HOED' vowel within the 60% duration. Also the 'HEED' and 'HAYED' vowels did not show much change in their roc within their 60% duration but they showed more change than the 'HID', 'HEAD', 'HAD', 'HARD', 'HOARD', 'HOOD' and 'HOED' vowels. This is an indication that the HOED' AND 'HAYED' vowels did not show much change in their formants compare with other the diphthongs. As shown in There was more change in the spectra for the vowel produced in 'SURE' than what was produced in 'TOUR' as can be seen in the vowel spaces already presented.

Looking at the spectra rate of change in the 60% duration, it was observed that the vowels produced in 'HAYED' and 'HAIR'D' were more suited with monophthongs than diphthongs even though there were some changes in their spectra.

Table 6. Spectra rate of change within 60% (in ms) duration

Test word	vowel	Spec roc 60%
heed	[i]	0.8
hid	[ɪ]	0.7
hayed	[eɪ]	0.8
head	[ɛ]	0.4
had	[æ]	0.3
hard	[ɑ]	0.5
hod	[ɒ]	0.8
hoard	[ɔ]	0.4
hoed	[əʊ]	0.5
hood	[ʊ]	0.6
Who'd	[u]	0.9
hide	[ai]	5.3
hoyed	[ɔi]	4.0
how'd	[aʊ]	2.7
hued	[ɪu]	7.8
haired	[ɛə]	0.9
toured	[ʊə]	3.1
sure	[ʊə*]	6.1
here'd	[iə]	3.8

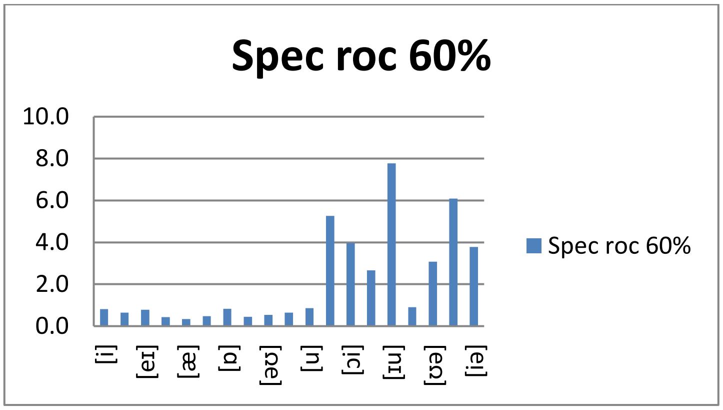


Figure 12. Spectra rate of change at 60% (in ms) of monophthong and diphthong vowels

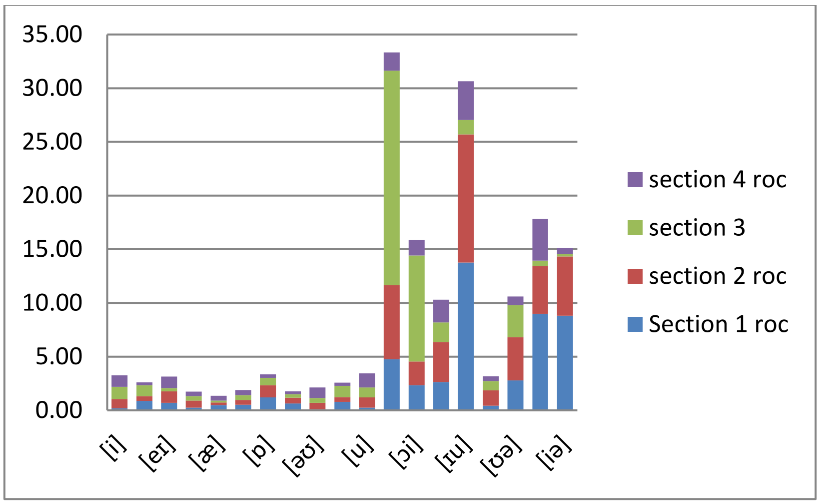


Figure 13. Spectra rate of change (in ms) in different sections of monophthong and diphthong vowels.

A look at Figure 13 shows the rate of change of the formant frequencies in the different sections of the vowels. Among the monophthongs, the rate of change in the first section (20% -35%) for the 'HEED' (0.19), 'HEAD' (0.24), 'HOED' (0.09) and the 'WHO'D (0.25) vowels were relatively very small indicating the least change in the spectra shape in the first section. There was much more spectra change in the first section for the vowel in 'HOD' (1.2) than there was for all the other monophthongs. This was followed by the 'HID' vowel (0.87), 'HOOD' (0.77), 'HOARD' (0.63) and 'HOD' (0.51).

In the second section (35% - 50%) of the monophthongs, the 'HAYED' (1.07), 'HOD' (1.12), 'WHO'D' (0.95) and 'HEED' (0.87) vowels showed a higher rate of change than in all the other monophthongs. For these vowels the rate at which the formants changed was higher in this section than it was found in the other vowels.

The third sections (50% -65%) of the monophthong vowels showed the least change in the 'HAD' vowel and the most change in the 'HEED' vowel (1.13) followed by the 'HOOD' vowel (1.03), 'HOOD' vowel (1.03), the 'HID'(1.01) vowel and the 'WHO'D' (0.93) vowel respectively. The vowels in 'WHO'D' (1.32), 'HAYED' (1.10), 'HEED' (1.06), and 'HOE'D' (0.99) repectively showed relatively higher rates of change in the final section (65% - 80%).

The rates of change of the formants at different sections of the monophthong vowels were seen to be non-uniform in the monophthong vowels. While there was higher rate of change in the first section for some monophthong vowels eg. [ɒ], other monophthongs eg. [u] showed higher rates of change in their final sections.

In the diphthong vowels, there was the highest change in the third section of the [ai] diphthong and this was followed by the rate of change in the [ɔi] diphthong. The least change in the spectral in the third sections of the diphthongs was observed in the dipohthong [iə] followed by [ʊə] and then [ɛə]. The spectra of the diphthong [ɪu] showed the highest rate of change in the first section of the vowel and this was followed by [ʊə] produced in the word 'SURE' and [iə].

Conclusion

This study sought to use acoustic parameters to describe the nature of diphthongs in Ghanaian English which hitherto had not seen any systematic phonetic investigation. The trajectory paths, spectral rate of change in different sections, and trajectory length of diphthongs and monophthongs were obtained in the study. Also, duration of the diphthongs and monophthongs in the different sections namely onset, offset, target 1, transition and target 2 were obtained. It was gathered that the duration of diphthongs though longer than those of the monophthongs could not be said to be twice as long as the monophthongs. All the monophthongs were produced shorter than their corresponding diphthongs with a significant difference ($p< .001$two-tail) except with the [æ] / [aɪ] and [æ] / [aʊ] pairs in which the diphthongs were not largely longer than the monophthongs.

The study showed that the duration of the different sections were such that for all the diphthongs except [ɛə] their onsets were relatively very short while the offsets were longer especially for the 'HOE'D', 'BOY'D', 'HAIR'D' and 'HIDE' vowels. This characteristic though may be due to the consonant types used at the beginning and end of the words. The frication noise in the sound /h/ was seen to have obscured part of the initial cues for the vowel thereby causing a shorter duration for it than the offset duration.

Target one was shortest for the vowel [əʊ] making it a rising diphthong. The target one for [ɔɪ], the 'HOY'D' vowel was the longest among the diphthongs and that makes [ɔɪ] a falling diphthong. The analysis showed that the vowels in 'HAY'D' and HOE'D had relatively very short target two (46ms and 15ms respectively) showing more of their target one. These vowels were thus characterized more as a monophthong than as a diphthong in this variety of English. As far as steady states are concerned each of the diphthongs had either a steady target one or target two. A very steady target one and target two in one single diphthong was not achieved in the data.

In the diphthongs, the study found that the transition period was the longest section in the diphthong trajectory. Therefore, much more variability was present in the transition period. This variability in transition period was the consequence of really short steady states (Target 1 and Target 2). Therefore, the diphthongs were seen to be characterized more by variability in the spectral shapes than in their steady states supporting, Holbrook and Fairbanks (1962) in their view that the diphthongs are better regarded as vowels with dynamics in their qualities rather than a combination of two monophthongs.

The movement of formants in the vowels in HAY'D [ei] and HOE'D [əʊ] especially in the F2 dimension were found to be very characteristic of the monophthong. Ellipses round those vowels showed slightly more variability in the F1 dimension than in the F2 dimension. The relatively small movement in the F1 dimension was characteristic of monophthongs such as [i], [ʊ], [ɔ] [u] and [ɒ] in the data.

The variability in the F1 and F2 dimensions revealed relative steady states in the Target one and Target two in most of the diphthongs although the steady states were rather short. This leads researcher to posit that two steady states exist only for some diphthongs. On the basis of just the F1, only the HERE'D vowel showed two steady states and could be classified as a vowel with two vowel qualities. The F2 on the other hand was found to be steadier in the target one and target two of almost all the diphthongs than the F1 was.

It showed in the data that the trajectories of the diphthongs did not really start and end with the quality of vowels with which they are transcribed. The diphthong [eɪ] as produced by the participants started close to [e] and ended just above [e] as is shown in the vowel spaces. In the trajectory for [aɪ], the initial vowel quality started at a position more front and higher than the position for [a] and ended just above [e] below the position for [ɪ] which has about the same height as [i]. The diphthong [ɔɪ] as well did not start as back as the monophthong [ɔ], the start position being as central as [ə] and the end position close to the position for [e]. Therefore, the positions of the diphthongs on the vowel space did not depict the symbols with which they are transcribed.

In the back-closing diphthongs, the second vowel quality did not quite get to the region for high back vowels. The diphthong [ɪu] produced in the word HUE'D showed a trajectory which was initiated at a position around [e] and ended at a position more front than the monophthong [ʊ] position in the vowel space. This diphthong could be transcribed as [eʊ]. The diphthong [aʊ] was found to be more like [aə] based on the start position and end position of its trajectory on the vowel space. There is also the diphthong of HOE'D [əʊ] which was produced more as a monophthong than a diphthong. The trajectory of this vowel started and ended at a position in the vicinity of [o].

Two the centering diphthongs investigated: HAIR'D [ɛə] and TOUR'D [ʊə] were produced as monophthongs. The start and end positions of their trajectories were very close. In both of those diphthongs the trajectory did not involve the position for the vowel [ə] which is part of the original diphthong. In the case of [ɛə] the vowel [ɛ] was realized and in the case of [ʊə], the vowel [ɔ] was realized. The third centering diphthong HERE'D [ɪə] had a characteristic closer to [ɪɛ].

In effect the study could not find any real centering diphthongs except in the production of [aʊ] which though not a centering diphthong in British English had a second vowel quality of [ə]. The diphthong in SURE'D [ʊə] (indicated with ʊiə* on the vowel space) was produced differently from the diphthong in TOUR'D. The trajectory of this vowel started at a point below the onset for [eɪ] and ended around the position for [ɔ] suggesting a diphthong like [eɔ].

The results of vector length measurements showed that among the monophthongs the vowel [eɪ] with a VL of 63ms showed more change in the formant movement than the monophthongs though the difference in VL is only 14ms. Therefore, this vowel was slightly more diphthongal than the monophthongs examined but relatively less of a diphthong. The 'HOED' vowel [əʊ] was shown to be even less diphthongal than the vowel [eɪ] showing less movement in the formants as indicated by its VL of 31ms. While [eɪ] was produced in the vicinity of [e], [əʊ] was produced in the vicinity of [o]. The vowels [ɔ], [ʊ] and [u] showed longer VL than the VL of [əʊ]. The values obtained showed some amount of spectral change for all the monophthongs though but in comparison with the values obtained for the diphthongs, those spectral changes were minimal.

The VL measurements indicated that the diphthong [ɛə] in 'HAIRED' had the least amount of spectral change indicated in the relatively small vector length of 38ms. This was an indication that the vowel [ɛə] was pronounced more like a monophthong produced in the vicinity of [ɛ]. The 'SURE' vowel [ʊə] showed the most spectral change with a VL of 945ms.

The amounts of spectral change were highest for the vowel [iu] in 'HUED' and that was followed by 'HIDE', 'HOYED', 'HOW'D' and 'HERE'D' respectively. An ANOVA results showed significant differences between the VL of these diphthongs and the VL of the 'HAYED', HOE'D and 'HAIRED' vowels.

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