Patterns of Vowel Production in Speakers of American English from the State of Utah

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PATTERNS OF VOWEL PRODUCTION IN SPEAKERS OF AMERICAN ENGLISH
FROM THE STATE OF UTAH

by

Larkin Hopkins Reeves

A thesis submitted to the faculty of

Brigham Young University

in partial fulfillment of the requirements for the degree of

Master of Science

Department of Communication Disorders

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BRIGHAM YOUNG UNIVERSITY

GRADUATE COMMITTEE APPROVAL

of a thesis submitted by

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This thesis has been read by each member of the following graduate committee and by majority vote has been found to be satisfactory.

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ABBREVIATIONS

PATTERNS OF VOWEL PRODUCTION IN SPEAKERS OF AMERICAN ENGLISH
FROM THE STATE OF UTAH

Larkin Hopkins Reeves
Department of Communication Disorders
Master of Science

The English spoken in the United States has traditionally been divided into six dialect regions: New England, Mid-Atlantic, Southern, Midland, Northern, and Western. The acoustic properties of American English spoken in the Southern and Northern dialect regions have been the subject of intense research, but the acoustic properties of the Western dialect region have not been analyzed as thoroughly. The umbrella term, Western American English, includes the English spoken in a large geographic area that stretches from Montana, Wyoming, Colorado, and New Mexico to the Pacific coast. Research that has focused on the Western dialect has included participants from several states, which discounts the idea that smaller dialectical differences may exist within the West.

This study describes several acoustic properties of American English as it is spoken in the state of Utah. Data collected from target hVd words were used to determine
vowel formant frequency patterns using F1 and F2 values of monophthongal and
diphthongal vowels, and calculate the vowel space area. Differences in vowel placement
and vowel space area were found between the English spoken in Utah and the Northern,
Southern, and Midland dialect regions. Similar to characteristics found in Western
English, an analysis of the vowel productions in speakers from Utah indicated a fronted
\(/\ddot{u}/\), as well as a near merger of \(/\alpha/\) and \(/\omega/\). However, the analysis also revealed
differences in Utah English when compared to the larger Western dialect region. In
particular it was found that, unlike descriptions of Western English, Utah English
speakers produced \(/\dddot{æ}/\) with a relatively higher F1 than \(/\alpha/\). The vowel space area of
Utah English was found to be smaller than the vowel space area of Northern English,
but larger than the vowel space area of Southern or Midland speakers.
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Introduction

Although extensive research exists regarding American English dialects (Bowie, 2008; Carver, 1998; Clopper & Pisoni, 2006; Frazer, 1994; Helquist, 1970; Labov, 1991), limited information is available about English dialects spoken in the Western United States. Research studies describing the Western American English dialect are rarely representative of the entire region. For example, Clopper, Pisoni, and deJong (2005) used speech samples elicited from one male speaker from Montana, one male speaker from New Mexico, two male speakers from California, one female speaker from Nevada, and three female speakers from California to draw conclusions about the dialect spoken in the West. In the study by Clopper et al., speech data were collected from less than half of the states in the Western dialect region. The large geographical area of the West often makes it difficult to gather data representative of the entire region. This challenge could mask the possibility that many smaller dialect regions may exist within the Western United States, which some experts deem the most heterogeneous dialect region in the United States (Labov, Ash, & Boberg, 2006).

Hagiwara (1997) explained that American English is constantly changing and varies considerably by geographic location. Hagiwara further asserted that a large number of studies need to focus on small regions to “fill a significant void in objective descriptions of American English . . . [and] lead to a better understanding of American English vowels” (p. 658). A comparison of several studies investigating the acoustic characteristics of vowels from different areas in the West would better describe the Western American English dialect and increase the chance of finding any smaller dialect regions. Thus, this study was designed to provide a description of American English as spoken by adults raised and currently living in Utah. The study examined the formant
frequency patterns of monophthongal and diphthongal vowels using F1 and F2 values, and the size of the vowel space area used by the participants.

Review of Literature

This review of literature describes the classification of American English dialects and the vowel production patterns which help determine dialectal and vowel space area differences. In addition, specific research regarding the Western American English dialect will be reviewed. For purposes of this study, the regional dialect of English spoken by native speakers living in Utah was referred to as Utah English and when used in isolation the term English was used to represent English spoken in the United States.

American English Dialects

Carver (1998) explained the term dialect as “a variety of language distinguished from other varieties by a set of grammatical, phonetic, and lexical features” (p. 5). American English dialects are typically classified into six regions: New England, Mid-Atlantic, Southern, Midland, Northern, and Western. The precise geographic boundaries of these dialect regions are not always agreed upon by experts. For example, Davis and Houck (1992) have argued that the Midland dialect is not a true dialect, but simply a transition between Northern and Southern American English. However, the research of Frazer (1994) and Johnson (1994) concluded that Midland speakers exhibit speech and language characteristics that are independent of both Northern and Southern American English.

While syntactic and lexical features of language can be important markers of dialect, researchers have commonly focused on phonetic differences among American English dialects. Clopper and Pisoni (2004b) examined several acoustic measures to identify factors that might be used to distinguish regional dialect across speakers of
American English. Speech characteristics such as fricative voicing and duration, rhotacization (r-coloring of a vowel), /u/ backness, /ou/ diphthongization, and /æ/ backness were all found to vary significantly depending on the regional dialect of the speaker. Differences in the rate and magnitude of vowel formant frequency change, vowel duration, and a speaker’s vowel space area have also been found to differ across regional dialects in American English (Jacewicz, Fox, & Salmons, 2007a).

American English dialects can be characterized as marked or unmarked depending on how perceptually distinct they are from General American English, or the dialect most commonly used in mainstream media throughout the United States. Some researchers consider Northern, Southern, Mid-Atlantic, and New England English to be marked dialects, whereas Midland and Western English are categorized as unmarked dialects (Clopper, Levi, & Pisoni, 2006; Clopper et al., 2005). A study by Clopper et al. (2005) found that Midland English was the least marked dialect because its only salient perceptual feature was the merger of /ɑ/ and /ɔ/. Unmarked dialects are sometimes collectively referred to as General or Standard American English, despite their heterogeneity (Gordon, 2004).

The English dialects spoken in the United States have a relatively high degree of mutual intelligibility. Unless listeners have previous linguistic experience with a particular regional dialect, they often have some difficulty assigning a specific dialect region to an unfamiliar speaker. Clopper and Pisoni (2004b) asked 18 university students to listen to three recorded sentences produced by speakers from six different American English dialect regions. After each sentence was presented, the listeners were instructed to indicate the region from which the speaker originated. Overall, the study participants
were only able to correctly identify the origin of the speaker approximately 30% of the time. In a follow-up study, participants correctly identified speakers with 42% accuracy when the number of dialect categories was limited to Northern, Southern, Mid-Atlantic, and General American English (Clopper et al., 2006).

In a similar study, participants who had lived in at least three different states before age 18 performed significantly better on a forced-choice dialect classification test than participants who had lived in only one state before age 18. The difference in accuracy was attributed to a more diverse linguistic experience during childhood (Clopper & Pisoni, 2004a). The lack of linguistic experience in hearing different English dialects may account for a tendency for listeners to perceptually merge the six American English dialects into New England, Southern, and Western English. This phenomenon may occur due to the lack of perceptual distinctiveness between some regional dialects (Clopper & Pisoni, 2004a; Clopper & Pisoni, 2007; Clopper et al., 2005).

**Vowel Production in American English**

American English dialects are primarily distinguished by the acoustic characteristics of the vowel system used in each region. Vowels contribute to the largest perceptual differences among dialects (Clopper & Pisoni 2004a, 2004b). Vowel production can be acoustically described using the source-filter theory of sound production. Many English speech sounds, including all vowel segments, utilize a sound source created by the vibration of the vocal folds. The articulators, especially the body of the tongue and the lips, alter the shape of the vocal tract. The altered shape of the vocal tract results in variations in the dimensions of the resonating cavities, thereby changing the amplification and attenuation of the sound source across a range of frequencies. For vowel-like sounds, these changes in resonance create a series of acoustic energy peaks
called formants. Listeners utilize the pattern of these formant frequencies as acoustic cues to perceptually distinguish between different vowel categories.

The relationship between the first and second formant frequencies (F1 and F2) is primarily determined by the relative height and advancement of the tongue. F1 decreases when the tongue is raised, which causes an increase in volume of the pharyngeal resonating cavity. Lower frequencies resonate better in a larger space, so the increased volume in the pharyngeal cavity results in relatively low F1 frequencies. F2 is affected by the length of the oral resonating cavity. F2 is lowered when the tongue retracts to create a longer oral cavity. Lip rounding can also increase the length of the oral cavity and lower F2 (Ferrand, 2007).

American English Vowel Inventory

Speakers of American English commonly use eleven monophthongal vowels, /i/, /I/, /e/, /ɛ/, /æ/, /u/, /ʊ/, /o/, /ɔ/, and /ɑ/, as well as the diphthongal vowels /əl/, /ɔu/, /au/, /eI/, and /oI/. Some dialects of American English produce the vowels /e/ and /o/ as diphthongs, namely /eI/ and /ou/. Monophthongs can be classified as (a) high or low, based on their F1 frequency; (b) front or back, based on their F2 frequency; and (c) tense or lax based on the amount of muscular tension during their production or whether they occur in open or closed syllables. Diphthongs result from gliding movements produced when the vowel begins in one position and ends in another position. The first vowel sound in a diphthong is called an onset; the second is called an offset. In the /oI/ diphthong, /o/ is the onset and /I/ is the offset.
Researchers have often sought to linguistically describe American English dialects by examining the patterns of vowel production. Labov (1991, 1998) explained that dialects are formed by systematic changes in vowel production. The usage of vowel production patterns can be influenced by several factors, including geographic isolation, cultural and social acceptance, as well as educational and economic incentives. Patterns of vowel production causing dialect differences have traditionally been described in terms of chain shifts, mergers, and changes in the vowel space area. Changes in vowel production patterns are often compared to the historic values of vowels from speakers of the same dialect.

*Chain shifts.* Chain shifts occur when the formant frequencies of multiple vowels systematically change, while each vowel maintains its perceptual distinctiveness. Chain shifts generally follow three unidirectional principles. First, tense vowels tend to rise, which causes a decrease in F1. Tense vowels are typically located along the outside of the vowel quadrilateral and tend to shift along a peripheral track. Second, lax vowels and the nuclei of upgliding diphthongs tend to shift downward within the vowel quadrilateral, resulting in an increase in F1. Lax vowels are found closer to the center of the vowel system and shift along a non-peripheral track. Third, back vowels move forward and F2 increases in frequency. This rule also applies when individual vowel qualities (i.e., onset and offset) are produced within a diphthong (Labov, 1991, 1998; Labov et al., 2006).

In a chain shift, vowels can move between the peripheral and non-peripheral tracks by either the *lower exit principle* or the *upper exit principle*. The track containing each vowel dictates which rules of chain shifting will be applied to the vowel. The lower exit principle states that the increasing of F1 or lowering of a non-peripheral vowel
within the vowel system will eventually result in the vowel entering the peripheral track. For example, the lower exit principle was found to affect the /æ/ vowel in Northern American English, whereby the word Ann is heard as Ian to speakers of other dialects. The upper exit principle generally affects tense vowels along the periphery of the vowel space. Instead of the vowel being produced on the peripheral track, it may shift to a more centralized position. Both exit principles initiate increased vowel category movement by creating open areas in the vowel space (Labov, 1991, 1998; Labov et al., 2006).

The chain shift in Northern American English is called the Northern Cities Shift (NCS) and is an example of lax vowels moving downward within the vowel quadrilateral (Labov, 1991, 1998; Labov et al., 2006). The NCS involves a clockwise rotation of the vowels /æ/, /ɑ/, /ɔ/, /ɛ/, /ɪ/, /ʊ/, and /ʌ/ in predictable, sequential stages (Clopper & Paolillo, 2006; Clopper & Pisoni, 2006; Clopper et al., 2005; Gordon, 2004). As found in Clopper and Pisoni (2004b), Figure 1 illustrates the NCS chain shift. Female speakers in the Northern region show more characteristics of the later stages of the NCS in their speech than male speakers.

As the tense vowel /æ/ rises along the front periphery of the vowel space in accordance with the first rule of chain shifting, space is created for subsequent shifts without causing phonemes to merge. Raising /æ/ initiates the movement of vowels in the NCS. Most speakers of the NCS have an F1 lower than 700 Hz and higher F2 frequencies for the vowels /o/ and /a/ than speakers of other American English dialects (Labov, 1991, 1998; Labov et al., 2006).
Figure 1. Vowel movement in the Northern Cities Shift.
The open space left by /æ/ moving upward becomes occupied by the /ɛ/ falling backwards along the non-peripheral track and /ɔ/ moving forward. Backing of /ɛ/ results in a lower F2 and is observed more often in large cities and in women speakers. Speakers in the advanced stages of the NCS produce a lower F2 for /ɛ/ than for /æ/, which is opposite of most other American English dialects. The forward movement of /ɔ/ is not caused solely by the NCS, but is observed in several young speakers in the North (Labov et al., 2006). The perceptual differences caused by the NCS are salient enough to cause communication difficulties with speakers of other English dialects. Labov (1991) provided the following examples of misunderstandings, “Ann as Ian, bit as bet, bet as bat or but, lunch as launch, talk as tuck, and locks as lax” (p. 19).

Recent observations of the NCS show that some speakers lower the F2 of /ʌ/ until it nears the back edge of the vowel space. The backing of /ʌ/ is most often found in younger speakers of the NCS. This is initiated when /ɛ/ moves backward into the space normally occupied by /ʌ/. As a result, /ʌ/ perceptually approximates /ɔ/, causing the word *busses* to be interpreted as *bosses* by speakers of other American English dialects (Labov, 1991, 1998; Labov et al., 2006).

Southern American English is characterized by the shifting and lengthening of several vowels across three stages, commonly referred to as the Southern Vowel Shift (SVS). Stage 1 of the SVS is initiated when the diphthong /ɑɪ/ is changed to a monophthong by removing the /ɪ/ offset. The resulting back vowel /ɑ/ then moves
slightly forward in accordance with the lower exit principle. In Stage 2 of the SVS, the space vacated by the change of /ɑI/ is filled when /eI/ becomes centralized and lowered by moving along the non-peripheral track. The /eI/ vowel becomes peripheral as it moves forward to fill the space vacated by /eI/. Because peripheral vowels rise, the F1 of /eI/ is higher than the F1 of /eI/ and the F2 frequency is higher for /eI/ than /eI/. The F1 and F2 values for /eI/ and /eI/ are reversed compared to most other American English dialects. Stage 3 is marked by a reversal of the vowels /i/ and /I/, following the same pattern and rules as /eI/ and /eI/ (Clopper et al., 2005; Clopper & Pisoni, 2006; Labov et al., 2006). As found by Clopper and Pisoni (2004b), Figure 2 illustrates the SVS chain shift.

Southern American English is also impacted by the fronting of several monophthongal vowels. Both /o/ and /ʊ/ tend to have higher F2 frequencies in Southern American English than in other American English dialects. Fronting /o/ causes a large overlap with /ʊ/, but the vowels remain distinct in spontaneous speech because of their formant trajectory (Clopper et al., 2005; Clopper & Pisoni, 2006; Labov et al., 2006).

**Mergers.** Mergers combine two vowels into one phonemic category, so the two original vowels are no longer perceived by listeners as different linguistic sounds. Mergers operate on the basis of two unidirectional principles: mergers are linguistically irreversible and mergers reduce perceptual distinction between vowel categories. In other words, two vowels become perceptually, and sometimes acoustically, indistinguishable. Mergers often initiate chain shifts because combining two vowels opens a space in the vowel system allowing a new vowel to occupy that space. Some common sounds that have already merged in the majority of American English dialects are (a) /w/ and /hw/, as
Figure 2. Vowel movement in the Southern Vowel Shift.
in wail and whale; (b) /ɔr/ and /ɔːr/ as in hoarse and horse; (c) different F2 frequencies of 
/u/, as in dew and do; and (d) intervocalic /r/, as in Mary, merry, and marry (Labov et al., 
2006).

Labov et al. (2006) has indicated that some vowel mergers are currently evolving 
in certain dialects of American English. For instance, the low-back merger of /ɑ/ and /ɔ/ 
is starting to emerge in the Midland dialect region, with about 20% of speakers exhibiting 
a merger of the two vowel categories. The merger of /ɑ/ and /ɔ/ is nearly complete in the 
Western region (Labov et al., 2006). Speakers in the North, Mid-Atlantic states, and 
South maintain a distinction between the two vowels in both speech perception and 
production. Speakers from the South display another type of vowel merger in /ɪ/ and /ɛ/ 
vowels before a nasal consonant, as in the words pin and pen. No other dialect region 
consistently displays this merger, although it can be found in isolated regions throughout 
the rest of the United States. Southern speakers also merge /ɪ/ and /ɨ/ before /l/, as in feel 
and fill. Speakers in Pennsylvania do not distinguish /ʊ/ and /u/ before word final /l/ 
phonemes, as in full and fool, but this distinction is often present in the surrounding 
dialect regions (Labov et al., 2006).

Vowel Space Area

The area of a vowel space represents the working area of the vowel system, 
meaning the maximal area of tongue movement typically used during vowel production. 
F1 and F2 frequencies of the American English corner vowels /i/, /æ/, /u/, and /ɑ/ create a 
vowel quadrilateral when they are graphed, as seen in Figure 3. Vowel quadrilaterals can 
be used to visually represent the extent of the vowel space. Since F1 and F2 frequencies
Figure 3. Vowel quadrilateral of standard American English.
are associated with tongue height and advancement during vowel production, the corner vowels of an individual can be graphed to represent the dimensions of their vowel articulations during speech. In addition to vowel quadrilaterals, researchers also use vowel multilaterals to represent the total articulatory area used for vowel production. In five-vowel polygons, the onset of the /oi/ diphthong is included in the vowel space calculation to provide a measure of the lowest F2 in the vowel system. Multilaterals in which the F1 and F2 frequencies of all 11 vowels are also used by researchers to represent the articulatory vowel space.

Vowel quadrilaterals show significant differences among Northern, Southern, and Midland dialects (Jacewicz, Fox, & Salmons, 2007b). The Northern American English dialect is one example of dialect affecting the vowel quadrilateral. Because /u/ has a lower F2 in the North, the area of the vowel quadrilateral increases. This causes the vowel space of the Northern vowel quadrilateral to be significantly larger than the vowel spaces of both the South or Midland dialect regions (Fox & Jacewicz, 2008; Jacewicz et al., 2007a). When the areas of five-vowel polygons are compared, they do not differ significantly among dialects. The vowel multilaterals of Northern speakers are larger than those of Southern or Midland speakers, but the differences are not significant. While the exact formant values of vowels differ among dialects, speakers of different dialects seem to use a similar amount of space when producing vowels (Fox & Jacewicz, 2008; Jacewicz et al., 2007a).

*Western American English*

Traditionally, the Western dialect region includes the states of Montana, Wyoming, Colorado, New Mexico, Idaho, Utah, Arizona, Nevada, Washington, Oregon,
and California. The Western dialect is typically classified as an unmarked American English dialect because its vowel system has been found to contain fewer distinguishing features than other dialects (Clopper & Pisoni, 2007). Labov et al. (2006) differentiated the Western dialect region from other English dialect regions based on the presence of a relatively complete low-back merger of /ɑ/ and /ɔ/ as well as /ʊ/ fronting without simultaneous /o/ fronting, but conceded that Western speakers are highly variable in their speech. Similar findings were also obtained from the Nationwide Speech Project, in which the Western speakers fronted /ʊ/ and merged /ɑ/ and /ɔ/ (Clopper & Pisoni, 2006).

Byrd (1994) found that speakers from the Western United States used a centralized /ə/ vowel less frequently than speakers from the Midland and South. Labov et al. (2006) found that the front vowels /i/ and /ɛ/ of Western speakers were slightly higher and more fronted in the vowel space than speakers of other American English dialects.

While most research regarding the Western dialect encompasses the entire region, some studies have focused exclusively on smaller regions within the West. Hagiwara (1997) examined monophthongal vowels produced by speakers from Southern California. When compared to research conducted by Hillenbrand, Getty, Clark, and Wheeler (1995) and Peterson and Barney (1952), the author found that Southern Californian speakers produced most vowels with lower F1 frequencies than speakers of Northern English and higher F2 frequencies than speakers of the General American English dialect.

Di Paolo and Faber (1990) examined the merger of tense and lax vowels before /d/ and /l/ of speakers from the Salt Lake Valley in Utah. Most speakers merged /u/ with /u/, /i/ with /ɪ/, and /ɛ/ with /ɛ/ before /l/. The authors speculated that the tense-lax
mergers may indicate a reversal of vowels, similar to vowel movements in Southern American English. The low-back merger found in Utah may also cause the merger of /ɔr/ and /ɑr/ (Helquist, 1970).

*Purpose of the Study*

The Western dialect region is one of the most heterogeneous and complex divisions of American English (Labov et al., 2006). While the vowel systems of Northern and Southern English have been described copiously by researchers, only a handful of studies have attempted to describe the Western dialect (Bowie, 2008; Di Paolo & Faber, 1990; Faber & Di Paolo, 1995; Hagiwara, 1997; Helquist, 1970; Labov et al., 2006). Most research about Western English has utilized a small conglomeration of speakers from multiple states, instead of focusing on a smaller portion of the overall region. The lack of more comprehensive research regarding vowel production in the Western United States raises questions about the correctness of including such an expansive geographical area under the umbrella of Western English. To explore the possibility of more refined distinctions within Western English, studies of smaller geographical areas are needed.

Thus, this study describes the patterns of vowel production in speakers of English originating from the Mountain West region, specifically the state of Utah. F1 and F2 frequencies gathered from both monophthongs and diphthongs were used to illustrate (a) vowel position within the vowel space using average F1 and F2 frequencies for each vowel, (b) diphthongization by measuring F1 and F2 of both onsets and offsets, and (c) vowel space areas determined by the vowel quadrilaterals created by the average F1 and F2 frequencies. The findings of this study were compared to vowel production data from
other dialect regions of the United States, including the Western region (Faber & Di Paolo, 1995; Jacewicz et al., 2007b; Labov et al., 2006; Weil, Fitch, & Wolfe, 2000).

Method

Participants

All participants were native speakers of American English. Speech recordings were collected from 35 female participants between the ages of 18 and 29 years, with a mean age of 22.1 years. All participants had lived in Utah since they were at least 18 months old. To ensure that the speaker's dialect accurately represented the spoken language of Utah, participants could not have lived outside of the state for longer than six consecutive months. Female speakers were used in this study because changes in dialect have been found to advance more quickly in young, female speakers (Clopper & Paolillo, 2006; Clopper et al., 2005). A summary of each participant's age, city of permanent residence, and how long each participant has lived at this address is found in Table 1. A map of Utah including the hometown of each participant is shown in Figure 4.

Participants were recruited from the Brigham Young University community and were not paid for their participation.

To qualify for the study, participants were required to pass a hearing screening at pure tone air conduction thresholds of 25 dB HL for the frequencies 0.5, 1.0, 2.0, 4.0, and 6.0 kHz in a quiet-room environment. Participants completed a questionnaire regarding their residential history, language background, and parent’s language background. No participants included in the study reported a history of any speech, language, or hearing problems. Five participants were disqualified from the study because of a reported history of hearing or speech impairment. Participants also read and signed an informed consent
Table 1

Demographic Data from Participants

<table>
<thead>
<tr>
<th>Participant</th>
<th>Age</th>
<th>Hometown</th>
<th>Years Lived in Hometown</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>25</td>
<td>Sandy</td>
<td>18</td>
</tr>
<tr>
<td>2</td>
<td>27</td>
<td>Lehi</td>
<td>16</td>
</tr>
<tr>
<td>3</td>
<td>21</td>
<td>Pleasant Grove</td>
<td>18</td>
</tr>
<tr>
<td>4</td>
<td>19</td>
<td>Murray</td>
<td>18</td>
</tr>
<tr>
<td>5</td>
<td>21</td>
<td>Murray</td>
<td>16</td>
</tr>
<tr>
<td>6</td>
<td>19</td>
<td>Lindon</td>
<td>11</td>
</tr>
<tr>
<td>7</td>
<td>22</td>
<td>Salem</td>
<td>11</td>
</tr>
<tr>
<td>8</td>
<td>29</td>
<td>Orem</td>
<td>29</td>
</tr>
<tr>
<td>9</td>
<td>27</td>
<td>Provo</td>
<td>25</td>
</tr>
<tr>
<td>10</td>
<td>18</td>
<td>Lindon</td>
<td>18</td>
</tr>
<tr>
<td>11</td>
<td>21</td>
<td>Sandy</td>
<td>20</td>
</tr>
<tr>
<td>12</td>
<td>18</td>
<td>Sandy</td>
<td>13</td>
</tr>
<tr>
<td>13</td>
<td>25</td>
<td>Orem</td>
<td>23</td>
</tr>
<tr>
<td>14</td>
<td>20</td>
<td>Riverton</td>
<td>16</td>
</tr>
<tr>
<td>15</td>
<td>19</td>
<td>Kearns</td>
<td>12</td>
</tr>
<tr>
<td>16</td>
<td>24</td>
<td>Pleasant Grove</td>
<td>23</td>
</tr>
<tr>
<td>17</td>
<td>23</td>
<td>West Valley City</td>
<td>20</td>
</tr>
<tr>
<td>18</td>
<td>25</td>
<td>Sandy</td>
<td>21</td>
</tr>
<tr>
<td>19</td>
<td>20</td>
<td>Lindon</td>
<td>18</td>
</tr>
<tr>
<td>20</td>
<td>19</td>
<td>Provo</td>
<td>19</td>
</tr>
<tr>
<td>21</td>
<td>29</td>
<td>Pleasant Grove</td>
<td>19</td>
</tr>
<tr>
<td>22</td>
<td>22</td>
<td>Salt Lake City</td>
<td>18</td>
</tr>
<tr>
<td>23</td>
<td>19</td>
<td>Bountiful</td>
<td>15</td>
</tr>
<tr>
<td>24</td>
<td>21</td>
<td>Kearns</td>
<td>8</td>
</tr>
<tr>
<td>25</td>
<td>26</td>
<td>West Valley City</td>
<td>21</td>
</tr>
<tr>
<td>26</td>
<td>18</td>
<td>West Valley City</td>
<td>18</td>
</tr>
<tr>
<td>27</td>
<td>20</td>
<td>Kaysville</td>
<td>20</td>
</tr>
<tr>
<td>28</td>
<td>22</td>
<td>Pleasant View</td>
<td>18</td>
</tr>
<tr>
<td>29</td>
<td>23</td>
<td>Sandy</td>
<td>17</td>
</tr>
<tr>
<td>30</td>
<td>21</td>
<td>Taylorsville</td>
<td>15</td>
</tr>
<tr>
<td>31</td>
<td>24</td>
<td>Pleasant Grove</td>
<td>10</td>
</tr>
<tr>
<td>32</td>
<td>25</td>
<td>Provo</td>
<td>14</td>
</tr>
<tr>
<td>33</td>
<td>22</td>
<td>Sandy</td>
<td>22</td>
</tr>
<tr>
<td>34</td>
<td>20</td>
<td>West Valley City</td>
<td>18</td>
</tr>
<tr>
<td>35</td>
<td>19</td>
<td>Provo</td>
<td>19</td>
</tr>
</tbody>
</table>
Figure 4. Map of Utah listing the hometown of each participant.
document approved by the Brigham Young University Institutional Review Board for Human Subjects Research (see Appendix A).

Procedure

Participants read a randomized list of 150 hVd words in the carrier phrase Say hVd again. The hVd tokens were: heed, hid, head, had, heard, hud, who’d, hood, hawed, hod, hide, howed, hey’d, hoed, and hoyed, which contain the American English vowels of /i/, /I/, /ɛ/, /æ/, /ɝ/, /ʌ/, /u/, /ʊ/, /ɔ/, /ɑ/, /aɪ/, /ɑʊ/, /eɪ/, /oʊ/ and /oʊ/. The speakers produced each sentence ten times, but only the first five occurrences of each vowel sound were analyzed. If the participant misread a sentence, the trial was rerecorded or not included in the analysis. The hVd context was used to decrease the possibility of coarticulation on the formant frequencies of the recorded vowels (Jacewicz, Fox, & Salmons, 2006).

Participants also read the Rainbow Passage (Fairbanks, 1960; see Appendix B) and answered a list of 12 questions (see Appendix C). The data collected from the passage and conversation tasks were not analyzed as part of the current study.

Recording Methods

Speech samples were recorded in a single-walled sound booth. More specifically, a high-quality DPA 4011 low-impedance, dynamic microphone and an Apogee Mini-me analog-to-digital converter were used for the recording of speech samples. The microphone was placed approximately 15 cm from the speaker’s lips during recording.

The speech tokens were recorded with a sampling rate of 44.1 kHz with a quantization of 24 bits and subsequently saved directly to an internal computer disk.
Following the recording of each stimulus token, a waveform display of the token was viewed to identify inappropriate recording levels (peak-clipping) or an insufficient recording window.

Acoustic Analysis

Frequency tracks for the first and second formants were extracted from the vowel targets using Praat acoustic analysis software, version 5.0.47 (Boersma & Weenink, 2004). Specifically, a linear predictive coding (LPC) based tracking algorithm (Burg method, 11 coefficients) was used to determine formant values for the vocalic segments at approximately 5 ms intervals. The LPC analysis employed a 25 ms Hamming window with 50% overlap and 98% pre-emphasis. Each token was checked to ensure that surrounding speech sounds were not audible in the analyzed segment, as well as visually inspected for accuracy, and where necessary, hand corrected prior to statistical analysis. The extracted formant values and associated time points were then saved to a text file for further analysis. In addition, the extracted formant tracks were evaluated with custom software designed to detect halving or doubling in the extracted formant tracks.

Using values from the extracted formant tracks, average F1 and F2 frequencies were calculated at eight different equidistant measurement points throughout each vowel’s overall duration (t1–t8). Thus, t1 was an average of the formant values in the initial 12.5% of the vowel’s duration and t8 over the final 12.5%. For the monophthongal vowels, values of F1 and F2 were extracted from the middle 50% of each vowel's duration by averaging the formant values from analysis windows t3 through t6. It was reasoned that the middle portion of the vowel exhibited a relatively steady state and was less influenced by the surrounding consonantal context. The formant frequencies of the onset and offset of diphthongal vowels were calculated at 25% (t2–t3) and 75% (t6–t7),
respectively. The transition slope of diphthongal vowels was computed by measuring the frequency difference between the onset and offset frequencies over time (Dromey, Nissen, Roy, & Merrill, 2008).

F1 and F2 frequency means were used to compute vowel space areas for each vowel following the methodology of Jacewicz et al. (2007b). Specifically, the average F1 and F2 frequencies for each speaker for two sets of three vowels /i, æ, a/ and /æ, u, i/ were used to calculate the vowel areas of the /i, æ, a/ and /æ, u, i/ triangles. The triangle areas were computed using Heron’s method (Jacewicz et al., 2007b), notated in the following equation:

\[
\text{Area} = \sqrt{s(s-a)(s-b)(s-c)} \quad \text{where} \quad s = \frac{a+b+c}{2}
\]  

The areas of the two triangles were then combined to estimate the area of the total vowel space.

Results

The formant frequency values and duration measures for each vowel were averaged across repetitions and individual speakers, resulting in an overall mean for each vowel type. Duration measurements were automatically calculated with a MatLab program based on the initial and final segmentation points of the vowel track.

Monophthongal Vowels

A detailed listing of the formant and duration values for the monophthongal vowels can be found in Table 2. The variability among speakers is represented by the
Table 2

*Duration and Formant Values for Utah English Monophthongs*

<table>
<thead>
<tr>
<th>Vowel</th>
<th>Duration (ms)</th>
<th>F1</th>
<th>F2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
</tr>
<tr>
<td>/i/</td>
<td>0.16</td>
<td>0.04</td>
<td>334.80</td>
</tr>
<tr>
<td>/I/</td>
<td>0.13</td>
<td>0.04</td>
<td>514.62</td>
</tr>
<tr>
<td>/ɛ/</td>
<td>0.13</td>
<td>0.03</td>
<td>722.89</td>
</tr>
<tr>
<td>/æ/</td>
<td>0.17</td>
<td>0.03</td>
<td>996.54</td>
</tr>
<tr>
<td>/ʌ/</td>
<td>0.14</td>
<td>0.03</td>
<td>780.38</td>
</tr>
<tr>
<td>/ɔ/</td>
<td>0.17</td>
<td>0.04</td>
<td>513.92</td>
</tr>
<tr>
<td>/u/</td>
<td>0.16</td>
<td>0.04</td>
<td>387.94</td>
</tr>
<tr>
<td>/ʊ/</td>
<td>0.14</td>
<td>0.04</td>
<td>553.01</td>
</tr>
<tr>
<td>/ɔ/</td>
<td>0.19</td>
<td>0.04</td>
<td>864.86</td>
</tr>
<tr>
<td>/ɑ/</td>
<td>0.18</td>
<td>0.04</td>
<td>870.93</td>
</tr>
</tbody>
</table>

aData from 21 participants were used to calculate /ʌ/.
standard deviations of the formant frequency values. To compare the results of this study with data collected in other research studies, the mean F1 and F2 formant values were used to create a vowel quadrilateral representing vowel placement in Utah English, as illustrated in Figure 5.

**Diphthongal Vowels**

A detailed listing of the formant frequencies for the onset and offset values, durations, and slope values of the diphthongal vowels can be found in Table 3. The vowel placement and slope values of the diphthongs are visually illustrated in Figure 6.

**Vowel Space Area**

The vowel space area was calculated from the mean F1 and F2 formant frequencies of the corner vowels using Equation 1. As shown in Figure 7, the /i, æ, a/ vowel triangle was found to have an area of .207 kHz$^2$, whereas the /æ, u, i/ triangle had an area of .338 kHz$^2$, for a total vowel space area of 546 kHz$^2$.

**Discussion**

**Chain Shifting and Mergers within Utah English**

When compared to previous descriptions of Standard American English (Hillenbrand et al., 1995; Labov, 1991, 1998; Labov et al., 2006), several examples of chain shifting are evident in the vowel production data collected in this study and are illustrated in Figure 8. The first rule of chain shifting, that tense vowels rise along the peripheral track, is observed with the onset of the /εI/ vowel. This study shows that the onset of /εI/ has a lower F1 than /I/, while the F1 of /I/ is lower than the onset of /εI/ in Standard American English. Additionally, Labov (1991, 1998) cited the reversal of /e/
Figure 5. Formant frequency placement of Utah English monophthongs.
Table 3

*Duration, Onset, Offset, and Slope of Utah English Diphthongs*

<table>
<thead>
<tr>
<th>Vowel</th>
<th>Duration (ms)</th>
<th>F1 onset</th>
<th>F2 onset</th>
<th>F1 offset</th>
<th>F2 offset</th>
<th>F1 slope</th>
<th>F2 slope</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td>M</td>
</tr>
<tr>
<td>/oI/</td>
<td>0.20</td>
<td>0.04</td>
<td>522.48</td>
<td>41.82</td>
<td>1052.73</td>
<td>136.14</td>
<td>459.67</td>
</tr>
<tr>
<td>/aI/</td>
<td>0.19</td>
<td>0.04</td>
<td>937.60</td>
<td>69.76</td>
<td>1668.00</td>
<td>135.83</td>
<td>603.63</td>
</tr>
<tr>
<td>/au/</td>
<td>0.20</td>
<td>0.04</td>
<td>935.09</td>
<td>77.96</td>
<td>1546.34</td>
<td>90.38</td>
<td>648.18</td>
</tr>
<tr>
<td>/eI/</td>
<td>0.18</td>
<td>0.04</td>
<td>489.68</td>
<td>38.05</td>
<td>2568.69</td>
<td>166.84</td>
<td>428.53</td>
</tr>
<tr>
<td>/ou/</td>
<td>0.18</td>
<td>0.04</td>
<td>567.75</td>
<td>62.28</td>
<td>1211.09</td>
<td>93.18</td>
<td>467.37</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 6. Formant frequency and slope of Utah English diphthongs.
Figure 7. Vowel space area calculations for Utah English.
Figure 8. Movement of vowels in Utah English.
and /I/ as an example of chain shifting in Southern American English. Because the F1 values of /e/ and /I/ are similar in Southern English and Utah English, the same chain shifting rule can be applied to the Utah vowel system. The second rule of chain shifting, that lax vowels move downward and toward the center of the vowel system, is evident in the /I/ and /ʊ/ vowels. The /I/ vowel not only has been reversed with the onset of /eI/, but also has become more centralized. The /ʊ/ vowel is centralized and has a higher F1 than might be expected in unmarked dialects. The F1 of /ʊ/ is about 15 Hz less than the F1 of the onset of /ou/, which may indicate the beginning of a reversal similar to the reversal of /eI/ and /I/. The last rule of chain shifting is that back vowels move forward. The back vowels /u/, /ɑ/, /oʊ/ all demonstrate slightly increased F2 frequencies. The most apparent example of a back vowel moving forward in Utah English is /ʊ/, but its forward placement might also be affected by the second rule of chain shifting. The fronted /ʊ/ was anticipated to appear in the vowel space of Utah English because it has been noted as a salient characteristic of the Western dialect in several studies (Clopper et al., 2006; Labov et al., 2006). The placement of the vowels from the data collected in this study is similar to the findings of Faber and Di Paolo (1995), which may indicate that the noted observations are not indicative of an ongoing chain shift, but the result of a completed shift.

An examination of the first two formant frequencies for /ɑ/ and /ɔ/ suggest that the low-back merger characteristic of Western English is nearly complete in Utah English. The acoustic differences between the F1 and F2 mean values of the two vowel
categories were found to be 6.0 Hz and 7.1 Hz, respectively. Anecdotally, several of the participants in this study commented that they could neither perceive nor produce the words *hawed* and *hod* differently.

**Comparison to Several American English Dialects**

It is of value to compare the formant frequency data found in this study to several other dialects of American English. Considering the similarities in elicitation context (i.e., hVd context) and analysis procedures, data from Northern and Southern English dialects were drawn from a study by Jacewicz et al. (2007b). Exact formant frequencies from the Jacewicz et al. study were not publicly available, so values were estimated from published vowel space figures. Comparisons between Utah English and Western English, as well as Utah English and Midland English, were based on findings from Labov et al. (2006). Unlike the elicitation context of the present study, the vowel production data from Labov et al. were obtained from spontaneous speech samples. Due to the limited number of research studies describing speech production in Western English, it was difficult to find a data set which was collected and analyzed in a manner similar to the present study. Consequently, any comparisons between the current study and Labov et al. (2006) should be interpreted with caution.

*Western English.* Although the Western dialect shows more evidence of a low-back merger when compared to other American English dialects, Utah English exhibits an even more complete merger of /ɑ/ and /ɔ/. In Utah English the acoustic differences between the F1 and F2 mean values of the two vowel categories were found to be less than 8 Hz, whereas in Western English the differences are reported to be 17 and 41 Hz, respectively.
The /u/ vowel in Western English is more fronted compared to the other back vowels, but the fronting in the Western dialect is not as advanced as the fronting in Utah English. Because /u/ is more fronted, the distance between /u/ and /o/ is greater in Utah English than in the general Western dialect. Another characteristic that distinguishes Utah English from the Western dialect is the relationship between the onset of /’elle/ and /’I/. The onset of /’elle/ has a lower F1 than /’I/ in Utah, but /e/ has a higher F1 than /’I/ in the Western dialect.

_Northern English._ The formant frequency patterns of vowel production in Northern and Utah English are illustrated in Figure 9. In general, the formant frequency values of the mid and high vowels are fairly similar between the two dialects. However, vowels produced in the lower portion of the vowel space show considerable differences. The relationship between /æ/ and /a/ is inverted between the two dialects; the /æ/ in the North has a lower F1 than /a/, but in Utah English /æ/ has a higher F1 than /a/. In Northern English, /a/ and /ɔ/ are distinct vowels and show no signs of merging, whereas in Utah English the /a/ and /ɔ/ vowel categories are almost completely merged.

The Northern English vowel space is larger than the vowel space calculated for Utah English due in part to the relatively low F2 of /u/ and high F1 of /a/. Following the calculations of Jacewicz et al. (2007b), the vowel space area was .670 kHz^2 for Northern English speakers and .546 kHz^2 for Utah English speakers.
Figure 9. Comparison of the vowel systems of Northern English and Utah English.
Southern English. A visual depiction of the vowel production patterns of Southern and Utah English are illustrated in Figure 10. Similar to Southern English (Clopper et al., 2005; Clopper & Pisoni, 2006; Labov et al., 2006), Utah English demonstrated the reversal of /e/ and /I/. In addition, the front vowels of both dialects (/i/, /I/, /e/, /æ/, and /æ/) have similar F1 values, but the vowels of Southern English generally have higher F2 values overall. The /æ/ vowel in Southern English illustrates the most dramatic contrast between F2 values of Southern and Utah English with a difference of nearly 420 Hz. Another dissimilarity in the vowel systems of Utah and Southern English is the distinction between /a/ and /o/ found in Southern English. In Utah English, the two vowels are practically indistinguishable. Comparing other back vowels between Utah and Southern English also yields interesting observations. The F2 distance between /ʊ/ and /o/ is much smaller in Southern English than in Utah English because the /ʊ/ in Utah English is extremely fronted compared to the other back vowels. In fact, the Utah /ʊ/ is fronted to the extent that its F2 is slightly higher than the /o/ vowel of Southern speakers. The F2 of the /ʊ/ vowel is nearly 580 Hz greater in Southern English than in Utah English. The /o/ and /u/ vowels also have much higher F2 values in Southern English. Overall, the majority of vowels in Southern English are more fronted than the vowels of Utah English because of their higher F2 values.

Figure 11 compares the /ol/ and /al/ diphthongs of Southern and Utah English. The onset and offset frequencies for the Southern diphthongs were taken from an analysis of single CVC words by Weil et al. (2000). Data for the /au/ diphthong were not available...
Figure 10. Comparison of the vowel systems of Southern English and Utah English.
Figure 11. Comparison of the diphthongs of Southern English and Utah English.
from Weil et al. (2000). The onsets of the diphthongs from each dialect begin in approximately the same position, but the Southern diphthongs have slightly lower F2 values. The /ɑI/ diphthong has a shorter distance between the onset and offset in Southern English than in Utah English, but the Utah /ɑI/ has a steeper slope. The distance between the onset and offset for the /oI/ vowel is approximately equal between the two dialects, but the direction of the slope is opposite as shown in Figure 11.

Compared to Utah English, the vowel space of Southern English is relatively compact. Following the calculations of Jacewicz et al. (2007b), the vowel space area was .401 kHz$^2$ for Southern English speakers and .546 kHz$^2$ for Utah English speakers. This difference in vowel space area is primarily caused by the lower F2 of /u/ for Utah English speakers.

**Midland English.** The comparison of vowel spaces between Midland and Utah English is limited because the data used to construct the Midland English vowel space were collected from conversational speech (Labov et al., 2006). In Midland English, /a/ and /ɔ/ are not merged, but they are closer in proximity than in Northern English or Southern English. The /u/ vowel in Midland English has a similar F1 frequency to Utah English, but the F2 of /u/ is greater in Utah English. In the Midland dialect, /o/ and /ɔ/ have similar F2 frequencies, but are distinguished by their F1 frequencies. The opposite is true for Utah English, because /o/ and /ɔ/ have similar F1 frequencies and differing F2 frequencies.
The vowel space area of Midland speakers reported by Jacewicz et al. (2007b) is similar to the Utah English vowel space area found in this study. The Midland vowel space area was calculated at .513 kHz² and the Utah English area at .546 kHz². These similarities may arise from the close geographic proximity between the Western and Midland dialect regions.

**Future Research**

Some of the variation among the previously discussed American English dialects may have been caused by differences in collection methods. Analyzing spontaneous speech samples from speakers of Utah English would provide information that could be better compared to the data collected by Labov et al. (2006). Additionally, researchers could analyze vowels by using an hVd context collected from speakers of other American English dialects as well as speakers from small geographical regions within the Western United States. Before Utah English can be separated from the Western dialect region, more research regarding individual regions of the West should be attempted to ensure that the differences found in this study are not due to the constantly changing nature of English (Hagiwara, 1997). This study does show that the Western dialect region is not as homogeneous as some studies assume (Byrd, 1994; Clopper et al., 2005; Clopper & Pisoni, 2004a, 2004b, 2006, 2007; Labov et al., 2006) and warrants more in-depth research concerning other Western regions. Studies of smaller geographical regions within the Western United States could also help determine the accuracy of the boundary of the Western dialect region and aid in the possible separation of the West into smaller dialect regions.

In addition, comparing the acoustic properties of vowels produced by young, middle-aged, and elderly speakers might yield valuable information about how the
Western or Utah English dialects differ as a function of age. This type of comparison may provide some insight into the evolution of dialect in the Western United States. Finally, the dialects of native English speakers from specific cultural groups within the West (e.g., Native American or Mexican American) could be analyzed to examine the role that cultural factors might play in determining an individual’s speech dialect.

Conclusions

The results of this study indicate that the vowel system of Utah English shares many characteristics with neighboring dialects of American English, but also exhibits some unique attributes. Differences in vowel placement and vowel space area were found between Utah English and the Northern, Southern, and Midland dialect regions. Several characteristics of Utah English are similar to characteristics found in Western English, like a relatively fronted /ʊ/ and a pronounced low-back merger of /a/ and /ɔ/. However, the results of this study also yielded some differences between Utah English and Western English. In particular, /i/ was higher and more fronted in Utah, while /ɛ/ was higher and more backed in the Western dialect. Utah English also displayed characteristics that are not common to the more general Western dialect, like the reversal of /I/ and onset of /eI/ and the F1 of /æ/ being higher than the F1 of /a/. The vowel space area of Utah English was found to be smaller than is reported with Northern English speakers, but larger than the vowel space area found for Southern or Midland speakers. However considering the variability between individual speakers and the possible influence of sociophonetic factors, the conclusions drawn from the data collected in this study may or may not represent the larger population of English speakers within the state of Utah.
Despite the limitations of the current study, the presented data provide additional insights into the vowel system of English speakers from Utah. The results of this study demonstrate the possibility of smaller dialect regions within the Western United States and also add information to the knowledge base of acoustic properties of vowels from speakers in the United States.
References


Appendix A

Informed Consent

Consent to be a Research Subject

Introduction
This research study is being conducted by Larkin Reeves, a graduate student in Communication Disorders at Brigham Young University. This work will be supervised by Dr. Shawn Nissen, who is a member of the faculty in the Department of Communication Disorders. The goal of the research is to examine speech patterns of speakers from the Mountain West region. You were selected to participate because you met the necessary language requirements (native English speaker from the Utah with no known history of a speech, language or hearing problem).

Procedures
Participation in this study will involve one visit of approximately 30 minutes to a Speech Research Laboratory in the John Taylor Building on the campus of Brigham Young University. You will be seated in a chair in a sound booth and will speak into microphone to record your speech. You will perform speaking tasks while we make recordings of your speech. Specifically, you will be asked to repeat a list of 14 phrases, repeated 10 times, read a short passage, and engage in a short conversation.

Risks/Discomforts
There are no known risks for participation in this study.

Benefits
By participating in this study, you will be given a free hearing screening. It is hoped that through your participation researchers will learn more about the English dialect that is spoken in the Mountain West.

Confidentiality
All information provided will remain confidential and will only be reported as group data with no identifying information. All data, including digital recordings of your speech will be kept in a locked storage cabinet and only those directly involved with the research will have access to them. Recordings will be assigned an ID number that will not be associated with the student’s name. Acoustic analysis will be conducted on the digital audio recordings and will only be available to investigative staff.

Compensation
No monetary compensation is offered. However, a summary of the findings of the study will be provided to you upon request.

Participation
Participation in this research study is voluntary. You have the right to withdraw at anytime or refuse to participate entirely without jeopardy to your class status, grade or standing with the university.
Questions about the Research
If you have questions regarding this study, you may contact Dr. Shawn Nissen at 801-422-5056, shawn_nissen@byu.edu.

Questions about your Rights as Research Participants
If you have questions you do not feel comfortable asking the researcher, you may contact Dr. Christopher Dromey, IRB Chair, 422-6461, 133 TLRB, dromey@byu.edu.

I have read, understood, and received a copy of the above consent and desire of my own free will and volition to participate in this study.

Name (Please Print) : ____________________________________________

Signature:_______________________________________________________
Date:________
Appendix B

The Rainbow Passage

When the sunlight strikes raindrops in the air, they act as a prism and form a rainbow. The rainbow is a division of white light into many beautiful colors. These take the shape of a long round arch, with its path high above, and its two ends apparently beyond the horizon. There is, according to legend, a boiling pot of gold at one end. People look, but no one ever finds it. When a man looks for something beyond his reach, his friends say he is looking for the pot of gold at the end of the rainbow. Throughout the centuries people have explained the rainbow in various ways. Some have accepted it as a miracle without physical explanation. To the Hebrews it was a token that there would be no more universal floods. The Greeks used to imagine that it was a sign from the gods to foretell war or heavy rain. The Norsemen considered the rainbow as a bridge over which the gods passed from earth to their home in the sky. Others have tried to explain the phenomenon physically. Aristotle thought that the rainbow was caused by reflection of the sun's rays by the rain. Since then physicists have found that it is not reflection, but refraction by the raindrops which causes the rainbows. Many complicated ideas about the rainbow have been formed. The difference in the rainbow depends considerably upon the size of the drops, and the width of the colored band increases as the size of the drops increases. The actual primary rainbow observed is said to be the effect of superimposition of a number of bows. If the red of the second bow falls upon the green of the first, the result is to give a bow with an abnormally wide yellow band, since red and green light when mixed form yellow. This is a very common type of bow, one showing mainly red and yellow, with little or no green or blue.
Appendix C

Interview Questions

1. What are you studying and why have you chosen this as a major?
2. What hobbies do you enjoy and why?
3. What is the single most important event that has happened during your lifetime and why?
4. What would you like to do with your future and why?
5. What do you think is the most important job a person could have and why?
6. Tell me about the last vacation you took.
7. Tell me about the last book you read.
8. Tell me about the last movie you saw.
9. If you could be anyone in history, who would you be and why?
10. Who is the one person you respect the most and why?
11. Where is your favorite place and why?
12. In life, what do you feel is most important?