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Cross-generational vowel change in American English

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ABSTRACT

This study examines cross-generational changes in the vowel systems in central Ohio, southeastern Wisconsin, and western North Carolina. Speech samples from 239 speakers, males and females, were divided into three age groups: grandparents (66–91 years old), parents (35–51), and children (8–12). Acoustic analysis of vowel dynamics (i.e., formant movement) was undertaken to explore variation in the amount of spectral change for each vowel. A robust set of cross-generational changes in /ɪ, ɛ, æ, ɑ/ was found within each dialect-specific vowel system, involving both their positions and dynamics. With each successive generation, /ɪ, ɛ, æ/ become increasingly monophthongized and /ɑ/ is diphthongized in children. These changes correspond to a general anticlockwise parallel rotation of vowels (with some exceptions in /ɪ/ and /ɛ/). Given the widespread occurrence of these parallel chainlike changes, we term this development the "North American Shift," which conforms to the general principles of chain shifting formulated by Labov (1994) and others.

The goal of this paper is to contribute to a better understanding of vowel change in American English by observing how vowel variants are transmitted over three generations of speakers. Vowel change has become a central topic in the emerging field of sociophonetics worldwide and has provided a rich basis for the examination of both internal (i.e., system-driven) factors and a variety of external (i.e., contact-driven) factors in different varieties of English in the world (e.g., Boberg, 2005; Cox, 1999; Labov, 1994; Labov, Ash, & Boberg, 2006; Labov, Yaeger, & Steiner, 1972; Torgersen & Kerswill, 2004; Trudgill, 2004; Watson, Maclagan, & Harrington, 2000; Watt, 2000). Depending on the research focus, studies were conducted to observe changes in a selected subset of vowels or in the entire vowel system. In the present study, we use a large sample size to examine how regional vowel systems have changed across three age groups of speakers: grandparents, parents, and children generations. The inclusion of

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children (8–12 years old) allows us to analyze the latest developments in the respective vowel systems apart from developmental factors present in children's productions of younger age.

Our approach to the study of vowel change is to explore vowel dynamics, a type of vowel internal variation also known as vowel-inherent spectral change (VISC) (Nearey & Assmann, 1986). That is, while examining more global positional vowel changes in the acoustic space, we also take into account the extent to which each vowel is "diphthongal" or "monophthongal." This is to establish whether the dialect-specific degree of diphthongization is also transmitted across generations. In particular, we ask the question of what constitutes a vowel change. Is it only a positional change found in vowel dispersion patterns in the acoustic vowel space or does vowel change also involve a change in its dynamic characteristics?

In much traditional historical phonology, sound changes including vowel shifts were formulated based on descriptive phonological analyses involving distinctive vowel features high/low and front/back, which allowed for capturing directional diachronic movement of vowels such as rising, lowering, fronting, or backing. Subsequent phonetic studies measured the relative positions of vowel nuclei and defined vowel rotations as positional changes in the two-dimensional F1 by F2 plane. From the phonetic perspective, the principles of vowel change (e.g., Labov, 1994) assumed that vowels are more or less "static targets" and their positional movement in the vowel space is the only change transmitted across generations. The present study draws attention to the fact that dynamic structure is inherent in the production of English vowels that must also be acquired by each successive generation. Thus, our current inquiry is to determine whether the dynamic structure remains intact in the process of sound change or whether positional vowel change also involves changes in vowel dynamics.

In this paper, we present cross-generational data that bear on both the shift in the relative positions of vowel nuclei as well as the systematic variation in the dynamic structure. Whereas the "static" positional changes inform us about the current direction of sound change, we also examine how formant patterns change over the course of each vowel's duration and seek to incorporate this variation into a more systematic study of vowel change. Though formant dynamics have been studied previously in the field of phonetics on selected subsets of American, Canadian, and Australian English vowels (e.g., Andruski & Nearey, 1992; Fox, 1983; Fox & Jacewicz, 2009; Hillenbrand, Getty, Clark, & Wheeler, 1995; Watson & Harrington, 1999), the relevance of this type of variation to cross-generational vowel transmission has not been generally addressed with the notable exception of a study of /u/-fronting in standard southern British by Harrington, Kleber, and Reubold (2008).

To study cross-generational vowel change, we selected three dialect areas in the United States: central Ohio (Midland), southeastern Wisconsin (Inland North), and western North Carolina (Inland South). The terms *Inland North* and *Inland South* refer to the labels given to the dialects spoken in these areas in the *Atlas of North American English* (widely known as *ANAE*, Labov et al., 2006). Each area is closely associated with distinct patterns of vowel variation and change that are discussed in depth in Labov et al.'s (2006) *ANAE* and are evidenced in other phonetic accounts such as Thomas (2001) and Clopper, Pisoni, and de Jong (2005). Though we expect that at least some of these reported dialect-specific vowel changes will be reflected in our data, we are particularly interested in determining if the inherent dynamic structure also undergoes systematic variations as a function of speaker dialect and generation. In our approach, we use the reported patterns of changes as a general guide and examine more closely how the positional changes found in our sample correspond to a specific pattern of variation in formant dynamics. We will review the widely accepted views on the vowel changes that each of these three dialects are reportedly undergoing.

Dialectal vowel variation and change in central Ohio, southeastern Wisconsin, and western North Carolina

Central Ohio, our first selected region, is typically seen as part of the Midland dialect area, although there is controversy about whether a "Midland" dialect actually exists (see Preston, 2003). It has traditionally been regarded as not being involved in any systematic chain shift. With regard to vowel patterns generally, Thomas (2001:82) characterized all of central and southern Ohio as consisting of "several weakly differentiated dialectal areas." Regardless of the area's status in dialectology, it is characterized by low back merger (i.e., loss of contrast between /ɑ, ɔ/) or near-merger of those vowels, cf. Labov et al. (2006:263–271) and Thomas (2001:94), among others.

With regard to /æ/, Labov et al. treated central Ohio, and Columbus in particular, as having a "nasal system," where /æ/ is raised before nasals, but "otherwise the nucleus remains in low front position" (2006:175,passim). Some other evidence suggests backing of /æ/ (Thomas, 1989, 2001:94), and real-time historical evidence shows that the vowel has historically not been raised in the region (Thomas [2006], though Thomas [1989] found raising in some speakers). However, more recent work in the Columbus area (Durian, 2009, 2010; Durian, Dodsworth, & Schumacher, 2010) has suggested that the region is, in fact, undergoing a chain shift involving /æ/, namely a form of the Canadian Shift (a systematic retraction of /æ, ɛ, ɪ/) in addition to low back merger.

Southeastern Wisconsin, the second region of our interest, has been widely regarded as the western edge of the Northern Cities Shift (NCS) area. An overview of the whole shift is given in Figure 1. In the NCS, raising of /æ/ is often supposed to be the earliest stage, while speakers also show fronting of /ɑ/, lowering and fronting of /ɔ/, backing of /ʌ/ and /ɛ/, with the weakest and likely last stage being lowering of /ɪ/ (though Labov (1994) and others have treated /ʌ/ backing as a possible last stage). Other sources, such as Gordon (2001:35; 2003:258–260), have given evidence for fronting of the low back vowel as the first stage, which then pushes /æ/ forward, a position now supported by McCarthy (2009). (For a detailed review of the relative and absolute chronology of the NCS, see Gordon, 2001:33–36.) Labov et al. (2006) reported the NCS to be fully developed in southeastern Wisconsin (showing the shift reaching to just

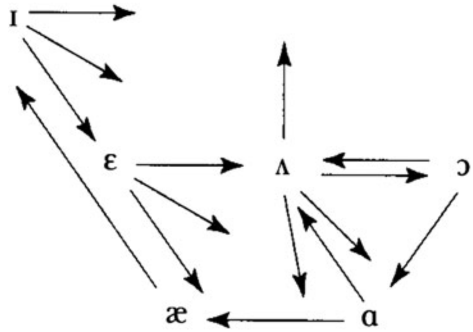

FIGURE 1. Schematic of the Northern Cities Shift based on Gordon (2001:197; 2003:255).

west of Madison), illustrating "advanced" NCS with a speaker from Kenosha, Wisconsin. Strong /æ/ raising in particular appears in the *ANAE* as a widespread pattern across Wisconsin, reaching westward into Minnesota and Iowa (2006:82, Map 10.5,passim).

More recent work within the region shows somewhat different patterns. For instance, in the Milwaukee area, Purnell (2010) found /æ/ raising and /ɛ/ lowering, but (using small caps for word classes, see also Labov et al. [2006:13–14]): "Movement among other vowels in the NCS is not as pronounced in southeastern Wisconsin as elsewhere in the NCS region. Bot may shift slightly forward, but not as far forward toward BACK" as it does in communities that show fuller NCS effects (2010:196). On this view, southeastern Wisconsin has a substantially more limited form of the NCS.[1] The subjects in the present study were largely from the Madison area, well west of Milwaukee, and thus closer to the edge of any NCS effects.

Another complicating factor for Wisconsin is chronological. Although the NCS is regularly thought of as a change in progress (e.g., Labov, 1994; Labov et al., 2006), at the heart of the NCS area, new work suggests that "the earliest developments may have run their course, at least in Chicago" McCarthy (2009:110), including /æ/ raising. That would be consistent with Purnell's findings. A final possible account for such patterns would be based on Labov (2007), who explains the inconsistently NCS-like patterns of St. Louis as the result of dialect-learning by adults rather than children. We will not pursue that further here.

Our third region under study, far western North Carolina, is associated with an advanced stage of the Southern Shift. In the *ANAE* formulation (2006:128,passim), this means monophthongization or glide deletion of /aɪ/ before obstruents (stage 1), reversal of position of /e/ and /ɛ/ (stage 2), and likely reversal of /i/ and ɪ/ (stage 3). With the raising and fronting of the two lax vowels here, /ɪ, ɛ/, the Southern Shift also includes diphthongization or "breaking" (Sledd, 1966). Although Labov et al. (2006:251–252) saw the Southern Shift as "reasonably stable" over apparent time, they identify some recessive tendencies over generations, especially in larger cities, suggesting that it is likely more robust in less urban areas. Other results show even greater diversity within the "South," broadly defined. Fridland (2002) found retreat of some aspects of the shift in Memphis, Tennessee, namely /i, ɪ/ reversal. Irons (2007a) found ongoing advance of the shift across generations in the rural and small-town areas of Kentucky's Eastern Coalfield region. Feagin (2003: especially 136–139) had already called attention to such reported differences in research findings and suggested that regional, methodological, and urban/rural factors may account for these.

Finally, another chain-shift–like pattern (called "solidarity chains" by Hock, 1991:157–158) is reported to be widespread across American English dialects, namely back vowel fronting, led by /u/ with /o/ trailing, and /ʊ/ often found to be included. Back vowel fronting appears to be advanced and pervasive in the South (Feagin, 2003), and widespread across the Northeast (Labov et al., 2006:143–144) and the Midland, though less advanced. Wisconsin and areas to the west, in contrast, are regarded as showing "resistance" to this trend (Clopper et al., 2005:1664, see also Labov et al., 2006:91, Map 10.14, passim). Labov (2010:36–40) summarized /u/ fronting as most advanced in the South and Midland and least in the North. At least some Midland varieties including Ohio, show fronting of /ʌ/ as well (Durian et al., 2010:175; Labov et al., 2006:266; Thomas, 1989).

In short, in each of these three regions, complex patterns of vowel change are reported over real and apparent time. The reference view provided by the *ANAE* contrasts with other, newer research results with regard to key chain shifts: (1) whether the Southern Shift in areas such as westernmost North Carolina is progressing or receding, (2) whether Midland varieties of central Ohio are involved in no chain shift or a Canadian Shift pattern, and (3) whether the NCS in southeastern Wisconsin is largely limited to /æ/ raising and /ɛ/ lowering or shows an advanced form of the shift, involving a full set of seven vowels.

Cross-generational sound transmission

We situate the present study of cross-generational vowel change within the general theoretical framework of Labov's model of transmission and incrementation (Labov, 2001:415–581; also Labov, 2007). In each dialect region, we examine how directional and dynamic vowel changes are implemented in terms of transfer of features from each older to each younger generation. Following the model's assumptions, we understand transmission as the product of the acquisition of language by children. Once the learned linguistic system stabilizes when children reach young adulthood, no structural changes to the vowel system are to be expected, and it is this system that is being transmitted to the next generation. In Labov's words, "structural patterns are not as likely to be diffused because adults do not learn and reproduce linguistic forms, rules, and constraints with the accuracy and speed that children display" (2007:349). Thus, the vowel system of young adults that will be transmitted to the successive generation should not undergo further structural changes itself if these adults stay in the same speech community.

In our study, we expect a change in the vowel system of each successive generation as a result of incrementation, that is, reorganization of the initially acquired system by young children during their preadolescent and adolescent years. In our present sample, we start with an initial system configuration in the grandparents' generation; the specific configuration is different in each dialect. We then expect to find a structural change in the successive parents generation brought about by incrementation. Children are expected to exhibit further reorganization in their vowel systems as a continuation of the transmission process. What we cannot predict here, however, are the connections between the transmission of systemic vowel features (including the degree of vowel-inherent spectral change) and stages of a dialect-specific chain shift. That is, we do not know whether each successive generation carries on the change by "implementing" and/or "continuing" (to use Labov's terms, 2001:466–581) a more advanced stage of the chain shift. It could be the case that the most advanced stage has already been reached by grandparents and other, more general principles of vowel change are operative in each younger generation. The present study will shed more light on this issue.

In selecting participants for the study, we were guided by their ties with their respective speech communities. We interviewed adults who were born, raised, and spent most of their lives in a given speech community and who were not engaged in frequent travel out of the area. Our selected speech communities were defined in terms of relatively narrow geographic areas. In each dialect region, we recorded participants from three-to-four adjacent counties, mostly professionals, who grew up in their respective regions, attended local schools and events, and had ties with the local religious and other social institutions.

In this paper, we focus on the basic, fundamental vowel systems of our speakers, using a set of words that were tightly controlled for phonetic context. Using the same speech material and obtaining speech samples under the same experimental conditions is the first critical step to a rigorous comparison of vowel dynamics across generations and dialects. By minimizing the effects of the immediate consonantal context and equally large effects of prosodic variation and linguistic stress (see Fox & Jacewicz, 2009, for experimental evidence of these effects), we were able to obtain a uniform set of data and a homogenous speech sample. Further work will examine whether and how the basic vowel systems obtained in this study differ from the systems constructed on the basis of naturalistic data from a typical sociolinguistic interview, which was also conducted with each present study participant.

METHODS

Speakers, materials, and procedures

Speech samples for this study were collected from 239 participants who were born, raised, and spent most of their lives in one of three dialect regions: central Ohio (78 speakers, mostly from Columbus and its suburbs), southeastern Wisconsin

(79 speakers, mostly from Madison and its suburbs) and western North Carolina (82 speakers, mostly from Sylva and adjacent areas). The participants fell into three age groups representing three generations of native residents of their respective speech communities that we define here as children (8–12 years old), parents (35–51), and grandparents (66–91). More details about their distribution by age and gender can be found in Table 1. Demographic information about each participant is presented in Appendix A (the online appendix can be viewed at http://cambridge.journals.org/LVC). The present participants were not biologically related to one another (with a few exceptions in Ohio and North Carolina). Rather, the age group brackets were selected solely based on possible (and most typical) parent and grandparent ages in relation to children 8–12 years old.

The participants were recruited using flyers; bulletin board postings; email; word of mouth; and announcements on radio and in local newspapers, churches, schools, and nursing homes. The recordings took place simultaneously in the three states in the years 2006–2008. Most participants were recorded at the university facilities in three locations: The Ohio State University, University of Wisconsin-Madison, and Western Carolina University. However, research staff members in each state were available to travel to homes and places outside the university to record participants who were unable to come to the designated testing location. This happened on several occasions, mostly with the older participants. In those cases, the same recording equipment was used as at the stationary locations to ensure uniform quality of the recordings in the entire sample. All participants were paid a nominal fee for their efforts.

During a one-hour testing session, each participant was asked to produce a set of citation form words, a set of prosodically structured sentences, and an unconstrained conversation discussing life experiences, family, regional issues, hobbies, and daily activities. For the present analysis of vowel systems, the data came from the first task only, that is, from citation form words. In this task, each

TABLE 1. *Distribution of participants into age and gender groups*

Dialect Region	Age Group	Number and Gender	Age Range (years)	Mean Age (SD) (years)
OH	C	16 M, 16 F	8–12	10.6 (1.6)
	P	12 M, 16 F	35–51	42.0 (4.6)
	GP	9 M, 9 F	68–87	70.2 (2.3)
WI	C	15 M, 16 F	8–12	9.5 (1.1)
	P	14 M, 16 F	36–50	44.1 (4.5)
	GP	9 M, 9 F	68–90	76.8 (6.2)
NC	C	16 M, 16 F	8–12	10.5 (1.2)
	P	16 M, 16 F	35–51	43.2 (4.9)
	GP	9 M, 9 F	66–91	73.1 (7.1)

NC = North Carolina; OH = Ohio, WI = Wisconsin; C = children, P = parents, GP = grandparents; F = female, M = male.

participant read a list of isolated hVd-tokens using the prompts *heed, hid, heyd, head, had, hod, hawed, hoed, who'd, hood, hoyd, hide, howed*, which contained 13 vowels of interest to the study: /i, ɪ, e, ɛ, æ, ɑ, ɔ, o, u, ʊ, oɪ, aɪ, aʊ/.[2] The citation-form vowels provided a common database for all 239 speakers because they were obtained in a uniform style free from effects of variable consonantal and prosodic contexts that introduce variation not only in the relative positions of vowels in the acoustic vowel space but also in their formant dynamics (Fox & Jacewicz, 2009; Hillenbrand, Clark, & Nearey, 2001). Each participant read three repetitions of each token presented in a random order for a total of 9321 items ($13 \times 3 \times 239$). The prompts appeared randomly on a computer screen, one at a time, and the tokens were recorded and digitized directly onto a hard disc drive at a 44.1-kHz sampling rate. A head-mounted Shure SM10A dynamic microphone was used, positioned at a distance of about 1.5 inches from the speaker's lips. The experiment was controlled by a custom MATLAB program and the researcher either accepted and saved the production or asked the participant for additional repetitions.[3]

Data analysis

Prior to acoustic analysis, the tokens were digitally filtered and down-sampled to 11.025 kHz. To capture the dynamic formant change in a vowel, the F1 and F2 frequencies were sampled at five equidistant temporal locations corresponding to the 20%, 35%, 50%, 65%, and 80% points in the vowel. The measurements of vowel onsets and offsets (which were located by hand), served as input to calculations of vowel duration and formant frequencies in the time course of a vowel. F1 and F2 values (based on 14th-order linear prediction coding (LPC) analysis and centering a 25-ms Hanning window at each temporal point) were extracted automatically using a program written in MATLAB that displayed these values along with the fast Fourier transform (FFT) and LPC spectra and a wideband spectrogram of the vowel. Two reliability checks were performed on all measurements by two different researchers. All automatically extracted formants were checked using the formant tracking option in the commercially available software program TF32 (Milenkovic, 2003), and any disagreements and errors in the analysis were resolved and hand-corrected when the corrections were considered necessary.

To assess the extent of formant movement in a vowel, we derived a measure formant trajectory length (TL), which is an approximate arc length of the formant trajectory in the F1 by F2 plane. Trajectory length is a measure drawn from a family of models using multiple sample points. The most widely used measure is that of the vector length, which estimates the distance in the F1-F2 plane between two sample points located close to vowel onset and offset such as 20%–80% or 20%–70% (e.g., Ferguson & Kewley-Port, 2002; Hillenbrand et al., 1995; Hillenbrand et al., 2001). The TL used in this paper is an extension of the two-measurement model and is defined as a sum of the lengths, in hertz, of the four separate vowel sections between the 20% and 80% points (i.e., 20%–35%, 35%–50%, 50%–65%, and 65%–80%):

$$TL = \sum_{n=1}^{4} VSL_n$$

where the length of one vowel section (VSL) is:

$$VSL_n = \sqrt{(F1_n - F1_{n+1})^2 + (F2_n - F2_{n+1})^2}$$

This five-point characterization of formant change in the F1-F2 plane provides a more detailed estimation of the amount of formant movement than the two-point model (see Fox & Jacewicz, 2009, for further discussion of advantages of the TL measure).[4] A longer TL implies more frequency change and thus greater formant movement in the plane. Using this measure, two-target diphthongs (such as /aɪ/) and one-target diphthongized vowels (such as /e/) are expected to have longer TLs than monophthongs (such as /i/). To interpret the dynamic variations for the reader, we will use in this paper the terms *monophthongization* and *diphthongization* to explicate the gradience of a speech signal without any reference to the number of the actual phonetic targets. For example, the monophthong /ɪ/ may become more monophthongal (or monophthongized) in the productions of parents compared with grandparents, which indicates simplification of its formant dynamics evident in a smaller amount of spectral change. In a similar way, we will refer to a diphthong as being more or less diphthongized or becoming more or less diphthongal in the productions of a given generation.

RESULTS

We begin the presentation of the results with cross-generational displays of mean relative positions of all 13 vowels in the two-dimensional (F1 × F2) acoustic vowel space and their dynamic formant patterns. In these plots, each vowel symbol is placed near the 80% point in a vowel indicating the direction of formant movement. Because the vowels were produced in the so-called neutral hVd context, the effects of consonantal environment are minimized and the dynamic change in a vowel reflects its vowel-inherent spectral change (e.g., Nearey & Assmann, 1986).[5] Given the well-known effects of vocal tract length on formant values (i.e., a longer adult vocal tract results in lower formant frequencies than a shorter child's vocal tract, *ceteris paribus*), if we are to directly compare the formants (and therefore the positions of the vowels in the vowel space) of these sets of speakers, we need to normalize the measured formant values. This normalization procedure should (1) eliminate variation caused by differences in vocal tract length while (2) preserving dialectal and cross-generational differences. In the current study, Lobanov's (1971) procedure, which converts formant values in hertz to *z*-scores for each individual speaker, was used. This is a normalization procedure that Adank, Smits, and van Hout (2004) found to be one of the most effective. However, because the resulting values are quite different from the original hertz values (and thus more difficult to interpret), we used the Thomas and Kendall (2007) approach to rescale the *z*-scores for each of the *i* vowels using the following formulae, where F^N_{1i} and F^N_{2i} refer to the normalized F1 and F2 values for the *i*th vowel and F^N_{MIN} and F^N_{MAX} refer to the minimum and maximum F^N values found across all vowels and all speakers (i.e., this is a speaker-extrinsic and not a speaker-intrinsic approach).

$$\text{rescaled and normalized } F^{RN}_{1i} = 250 + 500(F^N_{1i} - F^N_{1MIN})/(F^N_{1MAX} - F^N_{1MIN})$$

$$\text{rescaled and normalized } F^{RN}_{2i} = 850 + 1400(F^N_{2i} - F^N_{2MIN})/(F^N_{2MAX} - F^N_{2MIN})$$

The rescaled and normalized F1 values will range from 250 to 750 Hz, and the rescaled and normalized F2 values will range from 850 to 2250 Hz. All formant frequencies reported in the Results section of this paper represent rescaled normalized formant values. The unnormalized mean hertz values are reported in Appendix B (the online appendix can be viewed at http://cambridge.journals.org/LVC).

Cross-generational patterns of vowel dispersion

Figure 2 shows the vowel plots for three generations of Ohio (OH) speakers. Cross-generational changes are most evident in the vowels /ɪ, ɛ, æ, ɑ/. The vowels in *hid*, *head*, and *had* show the greatest amount of spectral change in the production of grandparents (GP), becoming increasingly monophthongized with each successive generation. A striking finding is that a further reduction of formant movement in /ɛ/ and /æ/ in children (C) corresponds to a change in the direction of formant movement in these two vowels. In addition, /æ/ shows lowering and retraction with each successive generation. Beginning with parents (P), we also notice a relation between /æ/ and /ɑ/. As the vowel in *had* lowers, the vowel in *hod* raises. The outcome of the /ɑ/-raising is its merger with /ɔ/, the low back merger. As can be seen, compared with boys, girls show a more advanced stage of both the lowering/backing of /æ/ and the merger. These results are consistent with the view that this part of the Midland region has near-merger or merger of the low back vowels (e.g., Thomas, 1989, 2001), and the advanced stage represented by the youngest females suggests ongoing progress of the merger.[6]

Another set of cross-generational changes in the OH data involves the back vowels /o, oɪ/ in *hoed* and *hoyd*. The onglide (i.e., the /o/-component of the diphthong, corresponding to the 22%, 35%, and 50% measurement points) raises with each successive generation. It is also articulated farther back in the oral cavity beginning with P. In parallel to the changes in /oɪ/, the onset of /o/ in

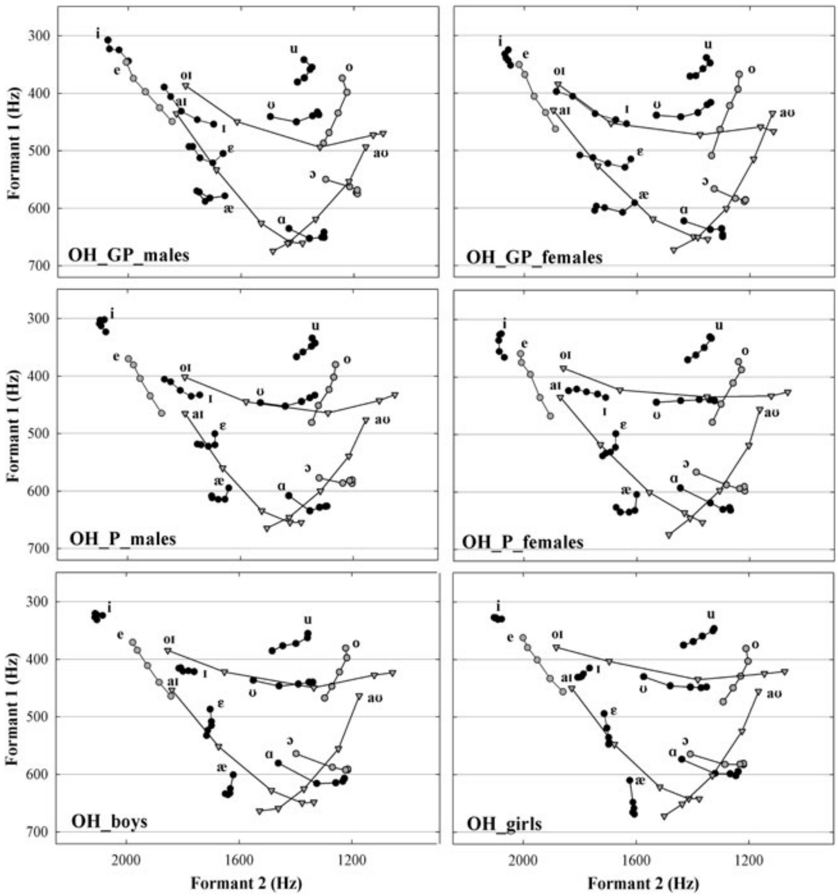

FIGURE 2. Cross-generational dynamic vowel dispersion patterns for Ohio (OH). Lines connect measurement points from 20% to 80% and vowel symbols are placed next to the 80% point. See text for further details. GP = grandparents, P = parents.

hoed raises with each generation, and compared with both P and GP, in C, the vowel is both more monophthongized and more back. Finally, whereas /o/ in *hoed* is backing in C, /ʊ/ in *hood* undergoes some fronting in their productions.

The cross-generational vowel dispersion patterns for Wisconsin (WI) are shown in Figure 3. At a first glance, the dominant feature that differentiates the WI and OH vowel systems are the positions of /u/ in *who'd* and /o/ in *hoed*, which are articulated farther back in WI speakers as compared with the fronted OH variants. The positions of these two WI vowels and the nature of their formant movement change little across generations, although some fronting can be detected in P- and C-males and some lowering of /o/ in P-and C-females. The /o/ seems to be more monophthongal in GP than in the younger generations.

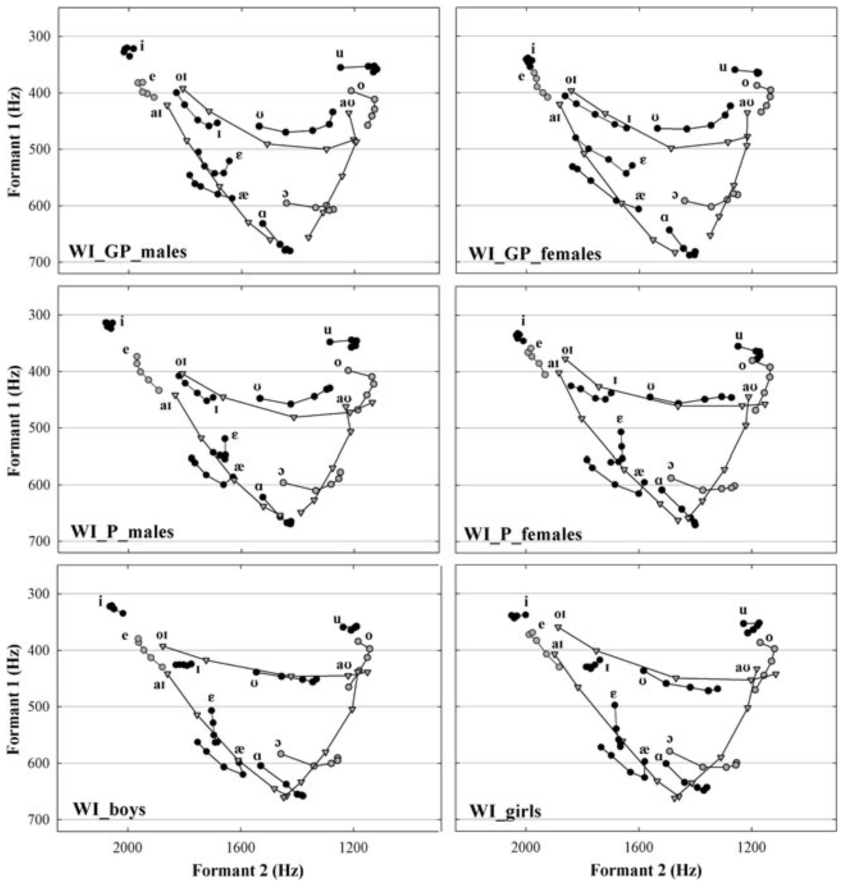

FIGURE 3. Cross-generational dynamic vowel dispersion patterns for Wisconsin.

These results confirm that this region shows resistance to back vowel fronting, which is otherwise widespread across the United States, and shows that the pattern is strong down to the youngest speakers.

Further differences between the WI and OH systems are in the dynamics of /e/ in *heyd* and /æ/ in *had*. The WI variant of /e/ is almost monophthongal in GP and becomes increasingly diphthongized with each successive generation. The monophthongal character of /e, o/ in the Upper Midwest, especially Wisconsin and Minnesota, is a salient feature of speech in the region for nonlinguists. A monophthongal pronunciation in the region has also been noted occasionally in the literature, particularly in Allen (1973–1976:II:21, 22), Labov et al. (2006:181, 183), and Thomas (2001:72). Our results suggest that this Upper Midwestern feature loses its strength over generations and both vowels become increasingly diphthongal. The WI vowel /æ/ has not only a greater amount of formant movement than the OH vowel does, but also shows a characteristic mark of the Northern breaking, a raised /ɛ/-like onglide and a lowered /æ/-offglide, following general patterns reported elsewhere (e.g., Labov et al., 2006; Purnell, 2010).

In general, the vowels in *hid*, *head*, and *had* seem to follow the same mechanism of cross-generational change as observed in OH, that is, reduction of formant movement in /ɪ, ɛ/ and lowering/backing of /æ/. However, it is evident that the vowel /æ/ does not lose its Northern breaking across generations, and the amount of its spectral change does not seem to be reduced. In spite of this, /æ/ clearly begins to lower in P and continues to lower in C. Furthermore, its offglide, corresponding to the 65%–80% region in the vowel, is clearly backing in C, thus following the pattern of change observed in OH. This lowering and backing of /æ/ affects the position of /ɑ/ in *hod*, which begins to rise in P. If this trend continues in WI, the low back merger seems inevitable in future generations of Wisconsin speakers. This set of vowel changes is substantially different from the NCS rotations. Although we clearly see NCS elements in the present WI sample such as lowering and centralization of /ɛ/ and the Northern breaking in /æ/, the current data show notable differences. In particular, /ɪ/ seems to be raising rather than lowering and /æ/ is clearly retracting and lowering. Thus, the linchpin change of the NCS, /æ/-raising, is absent over our generations. Similarly, the low back /ɑ/ is backing rather than fronting, whereas the NCS would crucially involve fronting of this vowel. In addition, along with the backing and raising of /ɑ/, we also find backing and raising of the onset of /aɪ/ in *hide* (i.e., at the 20%–35% temporal locations), which eventually "meets" the onset of /aʊ/ in C.

Finally, the cross-generational set of changes involving the WI variants of the back vowels in *hoyd* and *hood* parallels these in OH. The diphthong /oɪ/ raises and its onset retracts and the vowel /ʊ/ in *hood* undergoes successive lowering and fronting, which is more evident in women than in men and is most advanced in children. Fronting of /ʊ/ has been noted, for instance, by Hock as part of a general back vowel-fronting pattern in central Illinois (1991:142–158). We can also see it in the map of F2 of /ʊ/ in Labov et al. (2006:Map 10.14). Lowering of the vowel is noted by Labov et al. (2006:Map 10.13), but they expressly say that "the height of /u/ [= /ʊ/] does not play a prominent part in any of the sound changes discussed in the Atlas" (2006:90).

Turning to the North Carolina (NC) vowels displayed in Figure 4, we find a very different set of dialectal features. We will first focus on the vowel system of GP and will then observe the reorganization of the vowel space with each successive generation. First, the GP variants of /i, ɪ, e, ɛ, æ/ are in close proximity to one another and show a great amount of formant movement. We find a very diphthongal /e/, whose fronted nucleus "reverses" its position with /ɛ/. The dynamic patterns in the remaining four vowels demonstrate that breaking and the raised /æ/ is another characteristic mark of Southern American English.

Second, the nominal diphthongs are produced with far less spectral change than in both the OH and WI variants. We find a monophthongal /aɪ/ that also occupies the lowest position in the vowel space seen so far. The two remaining diphthongs,

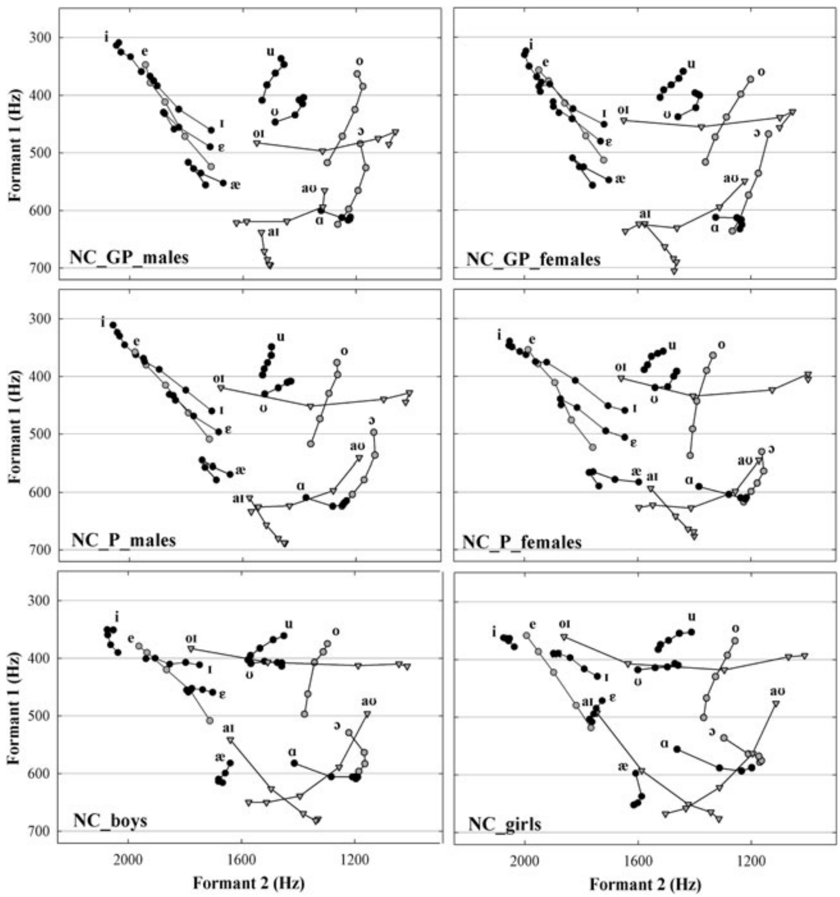

FIGURE 4. Cross-generational dynamic vowel dispersion patterns for North Carolina.

/aʊ/ and /oɪ/, exhibit reduced formant movement, especially in men. Glide weakening or loss, often referred to as monophthongization of "General American" diphthongs, has long been seen as a defining characteristic of Southern speech, as reviewed for all three diphthongs by Thomas (2003).

Third, we find a raised /ɑ/ in *hod* and a heavily diphthongized /ɔ/ in *hawed*, which has a very distinct character of formant movement indicating a production close to /ɑɔ/. This is what Labov et al. (2006:254, passim) termed the Back Upglide Shift, and which is seen as acting "to preclude the low back merger" (2006:303). The fact that the GP generation shows a powerful back upglide, while it recedes in younger speakers, would suggest that the resistance to low back merger could wane over time. Finally, the dispersion of the /o, u, ʊ/ group bears similarities with that in OH although the /u/ is even more fronted in NC and the /ʊ/ is more raised, which is consistent with what has been found in other studies.

In P, the following changes take place, which are more evident in women than in men: fronting of i, e/ and lowering and backing of /ɪ, ɛ/; lowering/backing of /æ/ and raising of /ɑ/; greater diphthongization of the three diphthongs /aɪ, aʊ, oɪ/; raising of /oɪ/; and further fronting of the /o, u, ʊ/ group. For this adult generation, the results indicate that the core Southern Shift is receding in this community, with regard to both glide deletion and the reversal of tense and lax front vowels. However, back vowel fronting continues unabated.

The set of changes in C include: fronting of /i/; loss of Southern breaking and monophthongization of /ɪ, ɛ, æ/; further lowering/backing of /æ/ and raising of /ɑ/; changing formant pattern in /ɔ/, which, especially in girls, corresponds to both OH and WI variants; greater diphthongization of /aɪ, aʊ, oɪ/; raising of /oɪ/; and further fronting of the /o, u, ʊ/ group. The loss of back upgliding—clearest in girls—suggests the possibility of future low back merger in the community. The present cross-generational progression toward the low back merger supports the findings reported by Irons (2007b) for Kentucky English. Irons proposed that "the mechanism underlying this low back vowel merger is back upglide loss, that is, the erosion of a phonological feature that has been a factor in resistance to merger in the South" (2007b:138). With regard to back vowel fronting, in girls, the variants of /u, o/ are clearly backing, which may indicate that fronting of these vowels reached its limit already in P-females and in boys, suggesting that no further fronting of these vowels ought to be expected without a categorical vowel change.

To summarize our observations thus far, we have found vowel dispersion patterns that are clearly dialect-specific as well as cross-generational changes that seem to be common across the three dialects. In particular, neither NCS nor Southern Shift appeared to be active in the selected regions, although some elements of either shift were clearly present. Instead, the cross-generational data revealed a new anticlockwise vowel rotation that was common to all three dialect areas. As an additional feature of this new development in the three regional vowel systems, the vowels /ɪ, ɛ, æ/ are found to be undergoing a common process of increased monophthongization (with the exception of WI /æ/) and /ɑ/ has been developing formant dynamics approximating those in the vowel /ɔ/. Figure 5 illustrates this process in greater detail by displaying the data from Figures 2–4 cross-generationally, separately for each dialect.

The cross-generational lowering/backing of /æ/ and the corresponding /ɑ/-raising is evident in all three dialects. However, in the case of /ɪ/ and /ɛ/, there is more variability. Whereas NC /ɪ, ɛ/ are clearly descending and retracting and WI /ɛ/ also shows the same trend in P (but not in C), the positional changes in /ɪ/, if any, are along the front-back dimension rather than low-high. Thus, the greatest cross-generational change in /ɪ, ɛ/, common across all three dialects, is the loss of formant movement and the positional changes may reflect some dialect-specific demands. We will return to this in the General Discussion. At present, we need to determine how strongly we can claim that variation in formant dynamics play a significant role in cross-generational vowel change. The

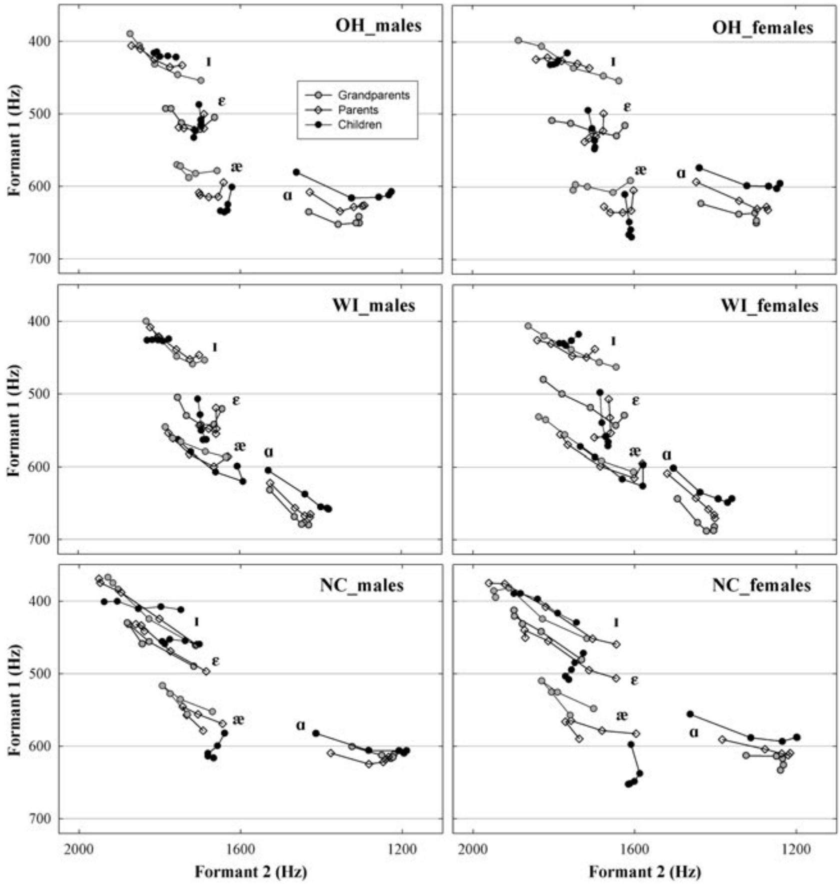

FIGURE 5. Cross-dialectal and cross-generational display of dynamic dispersion patterns for the vowels /ɪ, ɛ, æ, ɑ/.

statistical analysis of formant movement (TL) will help us to better understand its importance in the patterns already described.

Cross-generational patterns of formant dynamics

Mean TL values (and standard deviations) for each vowel broken down by dialect, age group, and gender are listed in Table 2. The TL differences were first examined using a series of one-way analyses of variance (ANOVAs) conducted separately for each vowel for each dialect. In these analyses, age group (generation: C, P, GP) and gender were the two between-subject factors. The effects of age group on changes in dialect-specific formant dynamics were of our particular interest. Following the significance of the main effect of age, Scheffé's multiple comparisons were used as post hoc tests. The second type of analysis used separate one-way ANOVAs to

TABLE 2. *Means and standard deviations (in hertz) for trajectory length broken down by dialect, age group, and gender*

Vowel	Token	Age/Gender	TL/OH	TL/WI	TL/NC
/i/	heed	GP_M	132 (52)	128 (54)	147 (60)
		P_M	103 (40)	94 (24)	153 (57)
		C_M	146 (30)	124 (45)	151 (52)
		GP_F	106 (24)	108 (26)	140 (75)
		P_F	126 (59)	91 (34)	123 (34)
		C_F	146 (49)	137 (62)	149 (37)
/ɪ/	hid	GP_M	220 (46)	201 (58)	295 (56)
		P_M	149 (42)	168 (41)	290 (65)
		C_M	131 (29)	118 (26)	232 (90)
		GP_F	282 (46)	255 (54)	293 (69)
		P_F	193 (52)	194 (61)	369 (60)
		C_F	126 (29)	108 (31)	218 (96)
/e/	heyd	GP_M	216 (53)	153 (43)	315 (53)
		P_M	188 (35)	150 (23)	327 (69)
		C_M	222 (72)	177 (53)	332 (60)
		GP_F	200 (50)	115 (42)	314 (65)
		P_F	208 (53)	137 (55)	327 (61)
		C_F	229 (67)	193 (61)	340 (60)
/ɛ/	head	GP_M	180 (36)	183 (71)	261 (62)
		P_M	117 (40)	120 (28)	253 (84)
		C_M	115 (32)	141 (40)	179 (73)
		GP_F	221 (40)	249 (53)	278 (89)
		P_F	125 (35)	155 (62)	325 (82)
		C_F	124 (37)	134 (35)	149 (53)
/æ/	had	GP_M	192 (85)	229 (100)	237 (85)
		P_M	132 (45)	196 (52)	198 (93)
		C_M	146 (34)	238 (84)	169 (49)
		GP_F	217 (59)	271 (47)	277 (69)
		P_F	158 (39)	271 (84)	287 (87)
		C_F	168 (47)	245 (45)	171 (49)
/ɑ/	hod	GP_M	207 (34)	162 (55)	153 (51)
		P_M	173 (96)	157 (30)	195 (66)
		C_M	298 (86)	216 (48)	290 (102)
		GP_F	207 (67)	173 (45)	187 (36)
		P_F	233 (58)	175 (40)	235 (64)
		C_F	258 (63)	234 (71)	324 (102)
/u/	who'd	GP_M	163 (40)	187 (69)	172 (53)
		P_M	129 (31)	153 (51)	151 (62)
		C_M	197 (62)	151 (54)	201 (51)
		GP_F	167 (60)	171 (42)	148 (53)
		P_F	152 (53)	168 (58)	141 (58)
		C_F	179 (62)	143 (47)	188 (56)
/ʊ/	hood	GP_M	225 (60)	301 (68)	169 (53)
		P_M	213 (44)	287 (60)	148 (53)
		C_M	247 (68)	245(46)	170 (59)
		GP_F	238 (71)	310 (61)	197 (91)
		P_F	249 (43)	319 (53)	160 (85)
		C_F	254 (58)	300 (53)	212 (49)
/o/	hoed	GP_M	206 (60)	182 (55)	250 (66)

Continued

TABLE 2. *Continued*

Vowel	Token	Age/Gender	TL/OH	TL/WI	TL/NC
		P_M	172 (34)	196 (68)	230 (57)
		C_M	173 (50)	191 (47)	224 (49)
		GP_F	215 (50)	161 (38)	258 (49)
		P_F	202 (38)	207 (63)	242 (41)
		C_F	181 (37)	190 (58)	239 (42)
/ɔ/	hawed	GP_M	206 (50)	213 (67)	227 (40)
		P_M	180 (84)	240 (50)	235 (110)
		C_M	275 (92)	257 (55)	246 (83)
		GP_F	241 (85)	229 (62)	246(73)
		P_F	237 (57)	265 (51)	239 (46)
		C_F	260 (86)	284 (72)	246 (86)
/aɪ/	hide	GP_M	526 (65)	472 (72)	119 (33)
		P_M	479 (65)	447 (93)	196 (113)
		C_M	570 (58)	484 (58)	401 (143)
		GP_F	634 (54)	526 (64)	224 (110)
		P_F	576 (62)	516 (45)	243 (130)
		C_F	523 (89)	545 (72)	528 (154)
/oɪ/	hoyd	GP_M	733 (86)	643 (80)	539 (80)
		P_M	760 (57)	695 (58)	713 (104)
		C_M	821 (74)	736 (70)	792 (150)
		GP_F	813 (58)	663 (70)	706 (117)
		P_F	832 (100)	746 (66)	726 (104)
		C_F	828 (77)	807 (50)	883 (72)
/aʊ/	howed	GP_M	402 (50)	331 (34)	425 (75)
		P_M	419 (62)	317 (45)	449 (84)
		C_M	444 (67)	383 (47)	500 (81)
		GP_F	462 (83)	288 (31)	486 (109)
		P_F	427 (67)	345 (69)	477 (102)
		C_F	433 (72)	416 (70)	468 (74)

TL = trajectory length; other abbreviations as in Table 1.

explore more global effects of dialect on TL of each vowel, disregarding the effects of age and gender. In this analysis, dialect was the only between-subject factor and Scheffé's comparisons followed as post hoc tests.

The statistical results are summarized in Table 3. Listed are significance values for the effects of age group separately for each dialect, and significant differences between age groups (C, P, GP) revealed by the Scheffé procedure. The effects of dialect (from the second analysis) are listed in the last column, which also includes significant differences between the dialects (OH, WI, NC) shown in Scheffé's post hoc comparisons. Although these post hoc comparisons were done on each vowel separately (and are thus relatively independent tests), given the large number of tests, we chose a relatively conservative α of .001. The significant results are summarized in Table 3. The effects of gender were mostly not significant and are not listed in the table. In general, female TLs were longer

TABLE 3. *Summary of statistical results for trajectory length for the effects of age and dialect*

Vowel/Token	TL/OH $F(2, 72)$	TL/WI $F(2, 72)$	TL/NC $F(2, 76)$	TL/Dialect $F(2, 235)$
/i/ (heed)	n.s.	n.s.	n.s.	F=7.85, p = .001 NC > WI
/ɪ/ (hid)	F = 52.23, p < .001 GP > P, GP > C, P > C	F = 37.47, p < .001 GP > P, GP > C, P > C	F = 15.35, p < .001 GP > C, P > C	F = 59.48, p < .001 NC > OH, NC > WI
/e/ (heyd)	n.s.	F = 7.94, p = .001 C > P, C > GP	n.s.	F = 183.13, p < .001 NC > OH, NC > WI, OH > WI
/ɛ/ (head)	F = 33.17, p < .001 GP > P, GP > C	F = 18.34, p < .001 GP > P, GP > C	F = 24.70, p < .001 GP > C, P > C	F = 41.53, p < .001 NC > OH, NC > WI
/æ/ (had)	F = 8.12, p = .001 GP > P, GP > C	n.s.	F = 11.10, p < .001 GP > C, P > C	F = 23.10, p < .001 WI > OH, NC > OH
/ɑ/ (hod)	F = 10.01, p < .001 C > P, C > GP	F = 12.07, p < .001 C > P, C > GP	F = 20.38, p < .001 C > P, C > GP	F = 9.93, p < .001 OH > WI, NC > WI
/u/ (who'd)	n.s.	n.s.	n.s.	n.s.
/ʊ/ (hood)	n.s.	n.s.	n.s.	F = 74.57, p < .001 WI > OH, WI > NC, OH > NC
/o/ (hoed)	n.s.	n.s.	n.s.	F = 24.28, p < .001 NC > OH, NC > WI
/ɔ/ (hawed)	n.s.	n.s.	n.s.	n.s.
/aɪ/ (hide)	n.s.	n.s.	F = 42.95, p < .001 C > P, C > GP	F = 86.06, p < .001 OH > NC, WI > NC
/oɪ/ (hoyd)	n.s.	F = 19.10, p < .001 C > P, C > GP, P > GP	F = 23.74, p < .001 C > P, C > GP, P > GP	F = 11.10, p < .001 OH > WI, OH > NC
/aʊ/ (howed)	n.s.	F = 18.16, p < .001 C > P, C > GP	n.s.	F = 48.75, p < .001 NC > OH, NC > WI, OH > WI

Abbreviations as in Tables 1 and 2.

than male TLs and significant differences were found only for OH *hid*, OH and WI *hide*, and NC *hoyd*.

As before, we begin with the analysis of the results for OH. The cross-generational changes in formant dynamics were significant only for the vowels /ɪ, ɛ, æ, ɑ/. For /ɪ/, all pairwise comparisons yielded significant differences between each successive generation, providing evidence that /ɪ/-monophthongization has been a continuous process spanning all three generations. The vowels /ɛ, æ/ change their dynamics in a similar fashion. However, the differences between P and C were not significant, suggesting that a substantial reduction of formant movement has already occurred in P and formant dynamics did not change much in C. For /ɑ/, we found a significant difference between the increased formant movement in C and either P or GP, and the latter two did not differ significantly from one another.

The results for WI show similar sets of significant cross-generational TL changes for /ɪ, ɛ, ɑ/. However, there were no significant differences for /æ/, confirming that the amount of formant movement in this vowel remained unchanged across the three generations. Also significant was the amount of spectral change in /e/ in C compared with either P or GP. This vowel, being known as almost monophthongal in WI, is clearly becoming diphthongized in the youngest generation. An interesting relationship can be found between the raising of the diphthong /oɪ/ in *hoyd* and a significant increase of its formant movement with each successive generation. This gradual and increased cross-generational diphthongization is achieved by both backing the onset of the diphthong and fronting its offset. Finally, there is a significant increase in formant movement in the diphthong /aʊ/ in *howed* in C, which most likely results from some lowering and fronting of its onset.

In the NC vowel system, the significant reduction of formant movement in the /ɪ, ɛ, æ/ set is clearly a change introduced more recently. The lack of significant TL differences between GP and P and inspection of the means in Table 2 indicate that Southern breaking is no longer present in C in /ɛ, æ/, and /ɪ/ has significantly reduced formant movement in C compared to the two older generations. Another recent change introduced in C can be seen in /ɑ/, which has a significantly greater formant movement. This change corresponds to similar patterns we have already seen in OH and WI in that children's variants of /ɑ/ were more diphthongal than those of adults, and there were no significant difference between the two adult groups. The two remaining NC vowels affected significantly by cross-generational changes are the diphthongs /oɪ/ and /aɪ/. The pattern of cross-generational change in /oɪ/ is the same as in WI in that a significantly greater diphthongization in each successive generation corresponds to the raising of the diphthong. The vowel /aɪ/ undergoes a diphthongization in C and is not produced as a monophthong as in GP and P. The amount of formant movement in the variant of /aɪ/ produced by NC girls is now comparable with that produced by OH and WI girls (see Table 2).

Overall, the statistical analysis of TL variation across age groups confirmed most of our initial observations, which were based only on visual inspection of the vowel plots. It also provided firmer ground for reaching conclusions about the importance of formant dynamics and their potential contribution to the process of cross-generational vowel change. Turning to the exploration of more global effects of dialect on formant dynamics of individual vowels (the second type of our analysis), we found significant effects of dialect for 11 vowels, except for /u/ and /ɔ/. This indicates that, despite significant cross-generational changes in each vowel system, formant dynamics are strongly affected by dialect. In most cases, NC variants had a greater formant movement compared with one or both dialects. The two exceptions were /ʊ/ and /aɪ/, which had the smallest amount of formant change.

GENERAL DISCUSSION

The acoustic analysis of vowel systems reported in this study revealed a robust set of cross-generational changes in /ɪ, ɛ, æ, ɑ/ that necessitates an extended discussion of this chain-shift–like development. We will first consider the positional vowel changes across generations and will then discuss these changes in relation to formant dynamics.

Figure 6 is a partial reproduction of the data from Figure 5 showing the location of each vowel's midpoint only, which, more or less, corresponds to a broadly defined "vowel target" or nucleus. As can be seen, there is almost no cross-generational change in the positions of /ɪ/ in OH and WI, although some fronting in WI boys can be detected. In both dialects, the location of the vowel in the acoustic space is comparable. This indicates that in OH and WI, the cross-generational change involves primarily its monophthongization and not a positional vowel movement. In NC, the vowel is retracting from its proximity to /i/, with a tendency to lowering. This movement seems to be unrelated to formant dynamics, as is evident in the female data.

The cross-dialectal differences are clearly manifested in /ɛ/. The vowel exhibits almost no positional change in OH (although slight centralization can be detected in men) but shows lowering and centralization in P in WI (more in women than in men), which is consistent with the direction of the NCS. Interestingly, there is no further retraction in WI once the vowel became monophthongized in P and the vowel seems to undergo some fronting in children. The cross-generational changes in /ɛ/ are most evident in the NC variant, which retracts from its high-front position into a more centralized and lower position with each successive generation. This positional change is much greater in women than in men and seems unrelated to the degree of diphthongization. The most dramatic change is in /æ/ which, in each dialect, is descending and backing with each successive generation. The degree of this change differs and can be as large as in NC women (where the vowel was highly raised in GP and now, in girls, is almost as low and as back as in OH children) or as small as in WI men, who nevertheless show a steady progression in the same direction. Finally, the vowel /ɑ/ shows the common cross-generational trend of raising and backing, despite the cross-

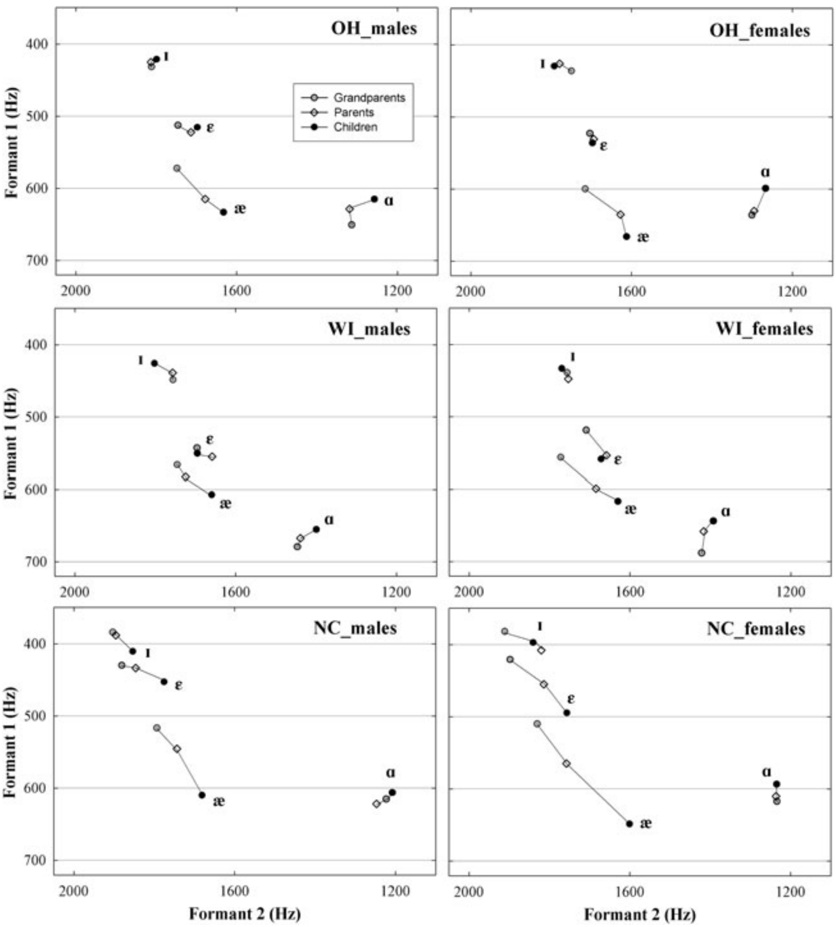

FIGURE 6. Cross-dialectal and cross-generational display of midpoint measurements for the vowels /ɪ, ɛ, æ, ɑ/. All data points are redrawn from Figure 5.

dialectal differences in its exact position in the acoustic space. This upward movement is rather unrelated to any change in formant dynamics.

Taken together, the cross-dialectal and cross-generational patterns found in this apparent-time analysis reveal a common mechanism underlying the set of changes observed here. The observed outcome is a chainlike anticlockwise rotation of all four vowels and the nature of this rotation needs to be characterized with greater precision. This shift is manifested most clearly in NC. In particular, in the production of the oldest speakers, all three vowels /ɪ, ɛ, æ/ are raised and fronted as a result of the Southern Shift. In the next generation, all three vowels show retraction and lowering, which is manifested more in women than in men. This conforms to the general view of the role of women in sound change, namely, that women are leading men generationally in this development. However, while

/ɪ, ɛ, æ/ are retracting and descending in the vowel space, female data show no change in the position of /ɑ/, indicating no involvement of this vowel at this stage. The final set of changes can be seen in children, showing no further change in /ɪ/ in girls (but retraction and lowering in boys) and further retraction and lowering of /ɛ, æ/. We now notice raising and some backing of /ɑ/, possibly in response to the low and back position of /æ/.

Elements of this movement across generations can be found in both OH and WI, although they do not manifest themselves as strongly and coherently as in NC. Because the vowels /ɪ/ and /ɛ/ were not involved in any shift in OH, their initial positions in the oldest speakers are lower than and not as fronted as in NC. Apparently, there has been no further lowering of both vowels in OH and some small variation in articulation can be detected in advancement rather than height. However, the raised position of /æ/ in the oldest OH speakers, especially in males, creates a condition for its lowering and backing, which indeed takes place in subsequent generations. The downward movement of /æ/ occurs simultaneously with the raising and backing of /ɑ/. The development in WI is in accord with those in OH and NC, showing no major variation in /ɪ/ (although some lowering and centralizing of /ɪ/ can be seen in adult males), centralization of /ɛ/ due to the NCS (and its lowering in adult females), and lowering and backing of the raised /æ/. The WI /ɑ/, which is low and not as back as NC or even OH variants, undergoes a steady raising and backing with each successive generation.

Considering now the relation between the positional vowel change and variation in formant dynamics, the results show a coherent set of events. While the vowel /ɪ/ in *hid* was diphthongized in the oldest age groups in all three dialect regions, we found a significant reduction of the extent of its formant movement in OH and WI parents groups. This reduction has been delayed by one generation in NC, and the change is occurring now in NC children. Comparing TL means, especially among the female groups (see Table 2), we find NC children values similar to those in OH and WI parents a generation earlier. Whereas NC children are “at the OH and WI parents stage,” both OH and WI now demonstrate further reduction of formant movement. The result of these cross-generational changes is a relatively monophthongal /ɪ/, whose position in the vowel space is basically the same in OH and WI. We understand these sets of changes in /ɪ/, including both positional movement in NC and simplification of the dynamic structure in all three dialects, as cross-generational progress toward the loss of distinctiveness of the dialect-specific phonetic features. Clearly, in children, the vowel has almost lost its diphthongal character, which is a most salient perceptual cue in maintaining a distinction between dialects in our oldest speakers. Results from a perceptual testing, currently under analysis in our lab, will verify our current understanding of why the vowel has become increasingly monophthongized in all three dialects.

The vowel /ɛ/ in *head* shows a very similar cross-generational development. However, given that this vowel, compared with /ɪ/, exhibits inherently smaller amounts of spectral change, it takes two generations in OH and WI (and not three) to reduce the formant movement sufficiently to produce a monophthong. Consequently, the /ɛ/ has already become a monophthong in OH and WI parents. The monophthongization of the NC variant of /ɛ/ takes place a generation later, in children, which is also consistent with the development of /ɪ/. We can also observe a beginning of a change in the direction of formant movement in NC girls, following the pattern in OH and WI children. Again, this increased monophthongization is most likely to reduce the phonetic contrast among the dialect-specific dynamic features that will be verified by the perception data.

The cross-generational changes in /æ/ in *had* in OH parallel those in /ɛ/. This is not the case in the WI variant, which remains fully diphthongized in all three generations, indicating that its Northern breaking is still a salient dialectal feature. In NC, the progressive monophthongization of /æ/ follows the same route as in /ɪ/ and /ɛ/, showing up in children (and not in adults). The NC girls have now essentially the same variant as OH girls. Finally, across all three dialects, the vowel /ɑ/ in *hod* shows an increase in formant movement in children compared with either adult group, suggesting that this is a recent development. That is, the quality of this vowel is changing in children, which is now more diphthongized and close to /ɔ/ in terms of the amount of formant movement (compare Table 2).

Clearly, there seems to be a common force underlying this general anticlockwise rotation, which operates in the same way regardless of the initial dialect-specific configuration in older adults. Obviously, we can see in these front vowels, the operation of Labov's Principle II, according to which lax vowels lower in chain shifts (formulated on the basis of Sievers [1876]). However, it is unclear at present what motivates this rotation other than the possibility of perceptual loss of dialectal distinctiveness in this particular subset of vowels. Certainly, the reduction of formant dynamics would point toward likelihood of this future outcome.

In parallel to the developments in the front vowels, the back /ɑ/ begins its route of raising and backing, until reaching the state of the merger with /ɔ/. In addition, a closer inspection of the back vowel space in NC (see Figure 4) indicates its successive expansion and raising of long vowels /aʊ/ and /oɪ/ that, along with /ɑ/, appear to be moving upward along the peripheral track. This development can be understood as an operation of Principle I which, again based on Sievers (1876), predicts a rising tendency of the long back vowels in chain shifts. To complete the anticlockwise rotation in the vowel space, the back vowels /u, o, ʊ/ undergo successive fronting in accord with Principle III, although this fronting may have reached its limit and is receding in NC girls. In OH, we also find the raising of /o, ɪ/ along with the expansion toward the back; although there is no raising of /aʊ/ (compare Figure 2). We also see a slight fronting of /u, ʊ/ but not of /o/, which seems to be backing. Finally, in WI, we can also observe the progressive raising of /oɪ/ along with its expansion toward the back of the vowel space and some fronting of /u, o, ʊ/ across generations (see Figure 3). Thus, it seems that the same set of principles is operative in each dialect, although the particular elements are executed with variable strength and weight in each respective vowel system.

How does this general anticlockwise development correspond to more recent reports involving American English? The changes in the /ɪ, ɛ, æ, ɑ/ set have been studied in Canada and were initially referred to as the Canadian Shift (Clarke, Elms, & Youssef, 1995). According to this first report, the Canadian /æ/ was retracting from its low-front position into low-central position, a movement triggered by the low back merger (*cat/caught*), which opened up an empty space in the vowel system previously occupied by /ɑ/. In response to this merger and the retraction of /æ/, /ɛ/ lowered to the position occupied by /æ/ and /ɪ/ lowered to the position made available by /ɛ/. Crucially, this pull chain comes to existence in response to the low back merger, which is thought to trigger the lowering and retraction of the entire front lax vowel system. Building on such earlier work, Gordon (2005) argued that retraction of the low front vowel creates a "margin of security" within the vowel space in response to low back merger. Bigham's (2009) study of southern Illinois vowels supported this at the overall community level, but some individual speakers showed retraction without merger, suggesting that retraction can be or become an independent sound change.

The results from 239 speakers presented in this paper do not conform to this version of the Canadian Shift because the lowering and retraction of /æ/ is not associated with the low-back vowel merger. That is, it occurs in dialects that both do (OH) and do not (WI, NC) exhibit the merger. On the contrary, our data support the vowel development reported by Boberg (2005), who provided acoustic and statistical evidence against the classic chain shift proposed in the original version of the Canadian shift. For the shift currently active in Montreal, Boberg emphasizes the parallel retractions of /ɪ, ɛ, æ/, calling it a "parallel shift" (2005:151; see the similar notion of "solidarity shift" already discussed). In this interpretation of the sound change, the retraction of /æ/ has not triggered the lowering of /ɛ/ as in a pull chain; rather, both /ɪ/ and /ɛ/ changed their positions in a parallel development with /æ/. The present study finds similar parallel developments in three very distinct varieties spoken in the United States. These results show retraction in whole communities without low back merger, suggesting even more independence between those two processes than Bigham argued for.

Given the widespread occurrence of these parallel shiftlike changes, we propose to term this recent and overarching development the *North American Shift*, which includes dialect regions in both Canada and the United States. An important component of this parallel anticlockwise rotation of the /ɪ, ɛ, æ/ set is monophthongization or reduction of dynamic spectral changes in these three vowels. At present, we await further reduction of formant movement in WI /æ/ and NC /ɪ/, the only two vowels that still show a substantial degree of diphthongization in children. In response to lowering, backing, and monophthongization of /æ/, we find increased diphthongization of /ɑ/ in children, which may signal an initial stage of its progression toward the low back merger, complementing its progressive raising and backing. In the present data, we find a higher-level unity across very distinct varieties that span the individual dialects. This unity subsumes but is not at odds with the diversity of dialects that is clearly visible in the strong presence of dialect-specific features across generations of speakers in each region.

It is yet unclear how the North American Shift corresponds to the developments reported in other English-speaking countries. For example, a similar anticlockwise rotation of /ɪ, ɛ, æ/ has been found in southeast England, which is viewed as a classic chain shift, originating with the lowering of /æ/ (Torgersen & Kerswill, 2004). This shift fits together with the fronting of /ʊ/ in this region, which can also be found across the North American dialects. Torgersen and Kerswill referred to Trudgill, who has argued that this shift is a drag chain that started with the lowering of /æ/. In their words, "Trudgill (2004), looking only at the three front vowels, considers this to be a drag chain beginning with TRAP. We suggest that the crowding of the vowel space, perhaps caused by the lowering of TRAP, forced STRUT to move back. If this is correct, the chain shift is one beginning in the middle of the chain, initiated by the lowering of TRAP" (p. 45). More reports from other parts of the English-speaking world are needed to provide further insights about the nature of this shiftlike rotation.

So far, our discussion has focused on structural factors without addressing possible social factors involved in the set of vowel changes found here. However, as claimed by Labov (2001:463), "there must be a social force that activates the shift and drives the increment." The basic social characteristics of the present participants are listed in Appendix A. These include both occupation and education level. All children were enrolled in elementary schools in the public school system, and adults represented a variety of educational and professional backgrounds. The oldest participants were mostly retired from their professions and lived at their homes or retirement facilities. The professional background data do not indicate major divisions within and across each dialect such as urban versus rural or related to socioeconomic status. In general, we expect the analysis of this parameter (i.e., occupation) to add little to a better understanding of the "social force" in the present study. The same holds true for the level of education.

Although the cross-generational and cross-dialectal patterns of variation found in this study are based on the most formal style of production, the results revealed substantial differences both in formant dynamics and vowel dispersion in the acoustic space as a function of age group and dialect. This indicates that linguistic forms associated with formal style in the production of the oldest adults differ from those in each successive generation. These results underscore the value of analyzing the citation-form speech in addressing questions about sound change. We also expect to find the same cross-generational patterns in vowel systems constructed on the basis of less formal, conversational speech. That is, the general vowel space along with the amount of formant movement in particular vowels will be considerably reduced in casual speech, especially when vowels occur in less prominent prosodic positions in the utterance (vowels in these positions will tend to centralize, cf. Agwuele, Sussman, & Lindblom, 2008; Lindblom, Agwuele, Sussman, & Cortes, 2007). Variation in speech tempo and consonantal context of the vowel will all contribute to reduction (or expansion) of the vowel space. Yet, within each type of variation, we expect the formant movement to be proportionally reduced (or expanded) although the basic pattern of dispersion within the vowel system itself is expected to remain the same. This aspect of cross-generational vowel change will be examined in our future work, using recordings of spontaneous speech collected from the present participants.

As for the effects of gender, another social factor controlled for in this study, we should not overlook the fact that, compared with male speakers, female speakers, in general, displayed somewhat greater formant movement in vowels. This was true especially for the diphthongs /aɪ/ and /oɪ/ and the /ɪ, ɛ, æ/ set (see Table 3). These vowels were more "diphthongal" in females than in males, perhaps reflecting a somewhat more exaggerated articulation in female speech. The gender-related differences may result from self-monitoring or perhaps from differences in the perception of task demands as suggested elsewhere (e.g., Beckford Wassink, Wright, & Franklin, 2007; Bell, 2001).

NOTES

1. An additional aspect of /æ/-raising—prevelar raising—clearly distinguishes Wisconsin from the (rest of) the Northern Cities area. See Bauer and Parker (2008), Purnell (2008), and Bauer (forthcoming). This body of work provides strong evidence that this process is distinct historically and phonologically from general /æ/-raising.

2. The vowel /ʌ/ in *hud* was originally included in pilot testing and then the prompt *hud* was overlooked at the stage of preparation of the final stimulus material and, therefore, is not included in the present study, but will be in future analyses based on the conversation data.

3. Although acceptable productions occurred most of the time, additional repetitions were obtained in case of poor quality recordings such as those due to voice quality, ambient noise, "false starts," laughing, and such.

4. The two-sample versus five-sample models are acoustic measures and do not imply that the listener might use these linear approximations to identify the vowel. Perceptual experiments are needed to test which model provides sufficient information about vowel quality.

5. A reviewer reminds us that the dynamic change in a later portion of a vowel may be indicative of coarticulatory timing differences between the vowel and the final consonant as a function of speaker age, which is not related to dialectal or cross-generational vowel change. A detailed analysis of coarticulatory events and articulatory data would be a desirable extension of the study of the acoustic formant changes reported in this paper to shed more light on this issue. At this point, we expect that some degree of formant movement starting at about the 70% point of a citation-form token will be attributed to a transitional movement toward a /d/ locus (and thus more susceptible to individual speaker variation) and not to a VISC per se. However, the time-varying changes of the vowel tract shape that produce VISC must include at least some consonantal effects because vowels are not normally produced with static configurations of the vocal tract shape. While admitting the possibility of coarticulatory interactions with VISC, we selected the most conservative *hVd*-frame, which, in phonetic research, is believed to introduce only marginal consonantal context effects.

6. In a perception study that used a subset of this study's tokens as stimuli, Garea (2009) found perceptual evidence for the progress of the merger. Young OH adults in their 20s gave higher identification rates for *hod* produced by the parents generation (78%, confused with *hawed* 20% of the time), whereas children's *hod* was identified as intended by the speakers only 58% of the time and its confusions with *hawed* rose to 37%.

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APPENDIX A

Basic demographic background of the participants (self-reported). Education level is coded as: 1 = elementary, 2 = high school, 3 = two-year college, 4 = four-year college, 5 = graduate degree. ID: C = child, P = parent, GP = grandparent.

APPENDIX A.

ID	Birth Year	Age at Testing (years)	Gender	Education	Occupation	Area
			Ohio Participants			
OH01_C	1994	12	F	1	Student	Piqua
OH02_C	1996	10	M	1	Student	Columbus
OH03_C	1994	12	F	1	Student	Columbus
OH04_C	1996	10	M	1	Student	Columbus
OH05_C	1995	11	F	1	Student	Columbus
OH06_C	1995	11	F	1	Student	Columbus
OH07_C	1995	11	F	1	Student	Columbus
OH08_C	1996	10	F	1	Student	Columbus
OH09_C	1999	10	M	1	Student	Columbus
OH10_C	1995	12	M	1	Student	Columbus
OH11_C	1997	10	M	1	Student	Columbus
OH12_C	1998	9	F	1	Student	Columbus
OH13_C	1997	10	M	1	Student	Columbus
OH14_C	1999	8	M	1	Student	Worthington
OH15_C	1997	16	M	1	Student	Worthington
OH16_C	1995	12	M	1	Student	Powell
OH17_C	1997	10	M	1	Student	Columbus
OH18_C	1995	12	M	1	Student	Columbus
OH19_C	1995	12	F	1	Student	Worthington
OH20_C	1997	10	M	1	Student	Westerville
OH21_C	1996	11	M	1	Student	Granville
OH22_C	1998	9	F	1	Student	Granville
OH23_C	1995	8	F	1	Student	Upper Arlington
OH24_C	1994	12	F	1	Student	Columbus
OH25_C	1998	9	M	1	Student	Westerville
OH26_C	1996	11	M	1	Student	Grove City
OH27_C	1998	9	F	1	Student	Grove City
OH28_C	1994	12	F	1	Student	Glenford
OH29_C	1998	9	F	1	Student	Columbus
OH30_C	1995	12	F	1	Student	Worthington
OH31_C	1998	9	F	1	Student	Columbus
OH32_C	1998	9	M	1	Student	Columbus
OH33_P	1959	47	F	3	Department office manager	Columbus
OH34_P	1958	48	M	4	Manager, sales marketing	Piqua
OH35_P	1958	48	M	2	Water plant operator	Columbus
OH36_P	1962	44	M	5	Bus driver	Columbus
OH37_P	1964	42	F	5	Homemaker, previous teacher	Lima

Continued

APPENDIX A. *Continued*

ID	Birth Year	Age at Testing (years)	Gender	Education	Occupation	Area
OH38_P	1968	39	M	5	Research assistant	Columbus
OH39_P	1969	38	F	5	Curator in research center	Columbus
OH40_P	1968	39	F	4	University staff	Worthington
OH41_P	1968	39	F	3	Preschool teacher	Powell
OH42_P	1970	37	F	5	Substitute teacher	Worthington
OH43_P	1965	42	F	4	Homemaker, previous teacher	Grandville
OH44_P	1965	42	F	5	Speech language pathologist	Columbus
OH45_P	1958	49	F	3	Nurse	Columbus
OH46_P	1969	38	F	5	Teacher	Grove City
OH47_P	1963	44	M	4	Graphic designer	Grandview Heights
OH48_P	1969	38	F	5	Homemaker	Hilliard
OH49_P	1968	39	F	4	Homemaker	Columbus
OH50_P	1960	47	F	5	Occupational therapist	Worthington
OH51_P	1958	49	M	3	Compliance facility director	Columbus
OH52_P	1965	42	F	4	Registered nurse	Columbus
OH53_P	1966	41	M	4	Policeman	Columbus
OH54_P	1967	43	F	4	Registered nurse	Columbus
OH55_P	1973	35	M	5	Teacher	Westerville
OH56_P	1972	35	M	4	IT technician	Hilliard
OH57_P	1968	39	F	4	University staff	Columbus
OH58_P	1964	44	M	5	Student	Ashville
OH59_P	1958	51	M	4	Consultant	Hilliard
OH60_P	1973	36	M	4	Retired, private investor	Columbus
OH61_GP	1938	68	M	5	Retired	Columbus
OH62_GP	1919	87	F	4	Retired homemaker	Columbus
OH63_GP	1935	72	M	5	Retired manager	Worthington
OH64_GP	1939	68	F	2	Retired	Columbus
OH65_GP	1935	72	F	3	Beautician	Columbus
OH66_GP	1931	76	F	3	Retired	Columbus
OH67_GP	1938	69	M	3	School bus driver	Columbus
OH68_GP	1932	75	F	5	Artist	Columbus
OH69_GP	1935	73	M	5	Retired	Columbus
OH70_GP	1934	74	M	2	Retired	Delaware
OH71_GP	1939	69	M	2	Retired	Columbus
OH72_GP	1937	71	F	3	Homemaker	Groveport
OH73_GP	1940	68	M	2	Retired telephone worker	Columbus
OH74_GP	1931	77	F	2	Homemaker	Columbus
OH75_GP	1932	76	F	3	Retired legal secretary	Columbus
OH76_GP	1940	68	M	3	Retired	Columbus
OH77_GP	1934	75	F	4	Retired teacher	Westerville

Continued

APPENDIX A. *Continued*

ID	Birth Year	Age at Testing (years)	Gender	Education	Occupation	Area
OH78_GP	1937	71	M	4	Retired fire fighter	Columbus
			Wisconsin Participants			
WI01_C	1998	9	F	1	Student	Madison
WI02_C	1997	10	F	1	Student	Madison
WI03_C	1996	11	F	1	Student	Madison
WI04_C	1997	9	F	1	Student	Madison
WI05_C	1997	9	F	1	Student	Monona
WI06_C	1999	9	F	1	Student	Madison
WI07_C	1999	8	F	1	Student	Madison
WI08_C	1995	12	F	1	Student	Madison
WI09_C	1998	9	F	1	Student	Madison
WI10_C	1998	9	M	1	Student	Madison
WI11_C	1999	8	F	1	Student	Madison
WI12_C	1999	8	F	1	Student	Madison
WI13_C	1996	11	F	1	Student	Madison
WI14_C	1999	8	F	1	Student	Madison
WI15_C	1998	9	M	1	Student	Middleton
WI16_C	1999	9	M	1	Student	Middleton
WI17_C	1999	9	M	1	Student	Middleton
WI18_C	2000	8	F	1	Student	Madison
WI19_C	1997	10	M	1	Student	Madison
WI20_C	1998	9	M	1	Student	Middleton
WI21_C	1999	8	M	1	Student	Middleton
WI22_C	1998	10	F	1	Student	Middleton
WI23_C	1999	8	F	1	Student	Madison
WI24_C	1997	10	M	1	Student	Madison
WI25_C	1997	10	M	1	Student	Madison
WI26_C	1997	11	M	1	Student	Madison
WI27_C	1998	10	M	1	Student	Madison
WI28_C	1996	11	M	1	Student	Madison
WI29_C	1997	11	M	1	Student	Menominee Falls
WI30_C	1998	10	M	1	Student	Madison
WI31_C	1998	10	M	1	Student	Madison
WI32_P	1968	37	M	5	Airport security	Madison
WI33_P	1960	46	M	3	PC repair business owner	Madison
WI34_P	1966	50	M	5	Physician	Madison
WI35_P	1964	41	M	5	Lawyer	Madison
WI36_P	1968	37	F	2	Computer technology	Madison
WI37_P	1959	46	M	3	Financial specialist	Madison
WI38_P	1967	39	F	5	Legal secretary	Lake Mills
WI39_P	1968	38	M	5	Researcher	Sun Prairie
WI40_P	1964	42	M	4	Unemployed	Madison
WI41_P	1967	39	F	5	Financial specialist	Madison

Continued

APPENDIX A. *Continued*

ID	Birth Year	Age at Testing (years)	Gender	Education	Occupation	Area
WI42_P	1970	37	F	5	Artist, currently student	Madison
WI43_P	1957	49	F	4	Defense investigator	Stoughton
WI44_P	1961	45	F	5	Trial attorney	Madison
WI45_P	1960	46	F	4	Health unit coordinator	Madison
WI46_P	1968	38	F	4	Health care manager	Madison
WI47_P	1968	38	F	5	Network engineer	Madison
WI48_P	1961	45	F	4	Small business owner	Oregon
WI49_P	1962	44	M	5	Electrical engineer	Oregon
WI50_P	1957	50	M	5	University professor	Madison
WI51_P	1966	41	F	5	Director of development	Verona
WI52_P	1967	39	F	5	Writer	Mt. Horeb
WI53_P	1970	36	F	4	Registered nurse	Madison
WI54_P	1960	46	M	5	Research program manager	Madison
WI55_P	1959	47	F	3	Correction officer	Fond du lac
WI56_P	1959	47	F	3	Part-time self-employed	Fond du lac
WI57_P	1958	49	F	5	Attorney	Madison
WI58_P	1966	40	M	5	Teacher (middle school)	Madison
WI59_P	1959	48	M	5	Student	Madison
WI60_P	1968	40	M	3	Clerk at Walgreens	Sun Prairie
WI61_P	1956	50	M	4	Business owner	Madison
WI62_GP	1930	76	F	4	Retired	Madison
WI63_GP	1928	79	M	3	Retired	Madison
WI64_GP	1936	70	M	5	Retired physician	Madison
WI65_GP	1936	70	M	4	Retired civil engineer	Madison
WI66_GP	1931	75	F	2	Retired	Monona
WI67_GP	1931	75	M	5	Retired	Madison
WI68_GP	1932	74	F	4	Retired	Madison
WI69_GP	1931	76	M	5	Professor	Madison
WI70_GP	1924	83	F	2	Florist, retired teacher	Madison
WI71_GP	1920	86	F	2	Retired registered nurse	Madison
WI72_GP	1924	83	F	4	Retired registered nurse	Monona
WI73_GP	1932	75	M	5	Retired VP purchasing	Madison
WI74_GP	1935	72	F	5	Registered nurse	Madison
WI75_GP	1939	68	M	3	Retired farmer	Sun Prairie
WI76_GP	1918	90	F	1	Retired	De Forest

Continued

APPENDIX A. *Continued*

ID	Birth Year	Age at Testing (years)	Gender	Education	Occupation	Area
WI77_GP	1922	85	M	5	Retired	Madison
WI78_GP	1934	73	M	2	Retired	Hartford
WI79_GP	1935	72	F	2	Retired	Menominee Falls
North Carolina Participants						
NC01_C	1995	11	M	1	Student	Cullowhee
NC02_C	1994	12	M	1	Student	Sylva
NC03_C	1994	12	M	1	Student	Sylva
NC04_C	1996	10	M	1	Student	Dillsboro
NC05_C	1995	11	M	1	Student	Sylva
NC06_C	1997	9	M	1	Student	Sylva
NC07_C	1995	11	F	1	Student	Sylva
NC08_C	1994	12	M	1	Student	Sylva
NC09_C	1995	11	M	1	Student	Sylva
NC10_C	1998	8	M	1	Student	Sylva
NC11_C	1994	12	M	1	Student	Tuckaseegee
NC12_C	1997	9	F	1	Student	Tuckaseegee
NC13_C	1996	11	F	1	Student	Sylva
NC14_C	1995	11	M	1	Student	Sylva
NC15_C	1997	9	F	1	Student	Sylva
NC16_C	1997	9	F	1	Student	Sylva
NC17_C	1997	9	F	1	Student	Sylva
NC18_C	1995	11	M	1	Student	Whittier
NC19_C	1994	12	F	1	Student	Sylva
NC20_C	1995	12	F	1	Student	Sylva
NC21_C	1994	12	F	1	Student	Sylva
NC22_C	1996	10	F	1	Student	Sylva
NC23_C	1994	12	F	1	Student	Sylva
NC24_C	1996	11	F	1	Student	Waynesville
NC25_C	1996	11	F	1	Student	Sylva
NC26_C	1998	9	F	1	Student	Sylva
NC27_C	1996	10	F	1	Student	Sylva
NC28_C	1995	11	F	1	Student	Sylva
NC29_C	1999	9	M	1	Student	Whittier
NC30_C	1996	9	M	1	Student	Sylva
NC31_C	1998	10	M	1	Student	Sylva
NC32_C	1999	9	M	1	Student	Waynesville
NC33_P	1957	49	F	3	Office assistant	Sylva
NC34_P	1959	47	F	4	Secretary	Waynesville
NC35_P	1962	44	F	3	Administrative assistant	Bryson City
NC36_P	1960	46	M	4	Buyer	Sylva
NC37_P	1959	47	F	5	Medical anthropologist	Sylva
NC38_P	1961	45	F	5	Credit counselor	Waynesville
NC39_P	1961	45	F	2	Medical records assistant	Bryson City
NC40_P	1927	43	F	3	Library assistant	Sylva

Continued

APPENDIX A. *Continued*

ID	Birth Year	Age at Testing (years)	Gender	Education	Occupation	Area
NC41_P	1961	45	M	5	Assistant superintendent	Waynesville
NC42_P	1968	38	F	3	Preschool teacher	Sylva
NC43_P	1956	49	F	3	Center director	Sylva
NC44_P	1967	38	F	5	Teacher/social work	Sylva
NC45_P	1964	42	M	3	Actor, musician	Sylva
NC46_P	1965	41	F	4	Teacher assistant	Sylva
NC47_P	1957	50	F	4	Social worker	Sylva
NC48_P	1968	39	F	3	Payroll specialist	Waynesville
NC49_P	1971	36	F	3	Childcare owner	Sylva
NC50_P	1963	44	M	5	Finance director, attorney	Sylva
NC51_P	1964	43	M	3	Contractor	Waynesville
NC52_P	1961	46	F	3	Book buyer	Waynesville
NC53_P	1957	50	M	3	Factory worker	Waynesville
NC54_P	1956	51	M	4	Real estate agent	Sylva
NC55_P	1959	48	F	3	Office manager	Sylva
NC56_P	1968	39	M	3	Law enforcement officer	Bryson City
NC57_P	1969	38	M	4	Highway patrol	Webster
NC58_P	1964	41	M	3	Military	Sylva
NC59_P	1959	47	M	2	Clerk at Lowes	Whittier
NC60_P	1959	48	M	4	County commissioner	Sylva
NC61_P	1971	36	M	4	Business owner	Sylva
NC62_P	1969	38	M	3	Minister	Sylva
NC63_P	1972	35	M	3	Military	Sylva
NC64_P	1972	35	M	3	IT support	Sylva
NC65_GP	1935	71	F	5	Retired university staff	Cullowhee
NC66_GP	1939	67	F	2	Retired office manager	Sylva
NC67_GP	1938	68	M	4	Retired	Sylva
NC68_GP	1938	68	M	3	Retired	Sylva
NC69_GP	1937	70	F	5	Retired teacher	Cullowhee
NC70_GP	1934	73	M	2	Retired equipment support	Sylva
NC71_GP	1932	75	M	3	Retired minister	Sylva
NC72_GP	1936	69	M	1	Retired farmer	Haywood County
NC73_GP	1929	78	M	3	Retired farmer	Haywood County
NC74_GP	1937	70	F	3	Retired teacher	Sylva
NC75_GP	1925	82	F	3	Public worker	Haywood County
NC76_GP	1920	87	M	5	Retired pharmacist	Sylva
NC77_GP	1937	70	F	2	Retired medical secretary.	Sylva
NC78_GP	1916	91	F	1	Retired homemaker	Jackson County

Continued

APPENDIX A. *Continued*

ID	Birth Year	Age at Testing (years)	Gender	Education	Occupation	Area
NC79_GP	1939	68	F	4	Retired social worker	Jackson County
NC80_GP	1932	74	F	2	Gift shop owner	Sylva
NC81_GP	1938	69	M	4	Supervisor, business	Sylva
NC82_GP	1942	66	M	5	Retired teacher	Sylva

APPENDIX B

Average formant frequency values (F1 and F2, in hertz) measured at five temporal locations (20%, 35%, 50%, 65%, 80%) in a vowel.

APPENDIX B.

	20%		35%		50%		65%		80%	
	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2
OH Boys										
heed /i/	379	3133	371	3146	360	3145	366	3131	368	3086
hid /ɪ/	558	2542	557	2523	569	2510	569	2469	571	2430
heyd /e/	657	2606	604	2693	543	2781	489	2856	462	2882
head /ɛ/	804	2335	785	2328	768	2301	753	2300	706	2310
had /æ/	1020	2200	1023	2181	1018	2165	1001	2165	950	2146
hod /ɑ/	959	1330	971	1340	976	1391	977	1524	905	1793
who'd /u/	493	1841	476	1762	467	1664	447	1578	432	1575
hood /ʊ/	607	1543	606	1567	613	1643	621	1781	601	1975
hoed /o/	665	1453	622	1400	569	1343	518	1288	485	1299
hawed /ɔ/	926	1305	923	1300	928	1317	918	1407	870	1664
hide /aɪ/	1048	1548	1050	1636	1004	1859	838	2250	635	2593
hoyd /oɪ/	574	972	584	1106	629	1561	565	2222	491	2627
howed /aʊ/	1079	1950	1067	1805	993	1615	845	1366	653	1218
OH Girls										
heed /i/	404	3207	399	3231	396	3238	399	3222	404	3181
hid /ɪ/	627	2600	627	2584	625	2567	616	2555	594	2508
heyd /e/	687	2714	637	2812	564	2910	515	2983	478	3013
head /ɛ/	892	2364	887	2362	868	2365	831	2377	775	2398
had /æ/	1149	2168	1171	2164	1164	2178	1124	2177	1038	2198
hod /ɑ/	1000	1370	1017	1387	1011	1429	1008	1547	952	1801
who'd /u/	504	1770	490	1699	469	1631	449	1552	441	1544
hood /ʊ/	664	1610	668	1651	666	1734	662	1889	627	2093

Continued

APPENDIX B. *Continued*

	20%		35%		50%		65%		80%	
	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2
hoed /o/	729	1483	674	1406	626	1349	568	1292	521	1309
hawed /ɔ/	972	1329	969	1330	972	1355	972	1475	933	1735
hide /aɪ/	1109	1678	1111	1753	1064	1975	891	2329	669	2650
hoyd /oɪ/	611	1021	618	1181	640	1698	567	2377	513	2767
howed /aʊ/	1180	1934	1132	1799	1021	1571	847	1347	687	1221
OH Males (P)										
heed /i/	313	2358	299	2384	294	2394	285	2391	284	2367
hid /ɪ/	434	2036	442	2003	464	1950	479	1891	475	1844
heyd /e/	522	2055	478	2119	434	2176	399	2210	383	2237
head /ɛ/	601	1858	603	1838	607	1798	602	1763	572	1763
had /æ/	735	1775	739	1773	743	1741	742	1704	714	1684
hod /ɑ/	759	1146	759	1153	760	1183	769	1234	733	1346
who'd /u/	378	1300	366	1264	351	1217	343	1194	332	1209
hood /ʊ/	476	1205	483	1233	493	1279	505	1370	497	1507
hoed /o/	546	1223	502	1184	461	1125	429	1096	398	1083
hawed /ɔ/	699	1006	692	1006	692	1018	700	1055	689	1183
hide /aɪ/	801	1288	800	1352	771	1507	662	1719	524	1922
hoyd /oɪ/	473	771	487	852	521	1131	495	1583	431	1923
howed /aʊ/	817	1469	788	1347	719	1178	627	1023	535	932
OH Females (P)										
heed /i/	436	2798	417	2833	380	2838	362	2831	359	2821
hid /ɪ/	551	2373	546	2318	557	2254	564	2180	576	2125
heyd /e/	638	2492	576	2561	494	2626	455	2686	425	2692
head /ɛ/	776	2145	767	2123	763	2093	746	2060	701	2057
had /æ/	951	2060	968	2030	969	1969	963	1927	908	1916
hod /ɑ/	962	1286	953	1292	960	1337	937	1421	886	1620
who'd /u/	447	1570	431	1516	406	1461	373	1412	368	1419
hood /ʊ/	585	1387	582	1420	582	1489	586	1613	592	1776
hoed /o/	661	1399	598	1342	525	1263	479	1207	451	1226
hawed /ɔ/	897	1189	881	1194	888	1225	876	1315	833	1520
hide /aɪ/	1004	1472	972	1594	902	1829	738	2159	575	2431
hoyd /oɪ/	556	902	567	1008	571	1436	548	2026	474	2411
howed /aʊ/	1044	1702	989	1560	895	1359	741	1162	616	1088
OH Males (GP)										
heed /i/	333	2138	310	2185	308	2234	288	2243	287	2240
hid /ɪ/	395	1960	417	1926	450	1873	472	1791	482	1709
heyd /e/	478	1916	445	1982	407	2058	375	2117	337	2152
head /ɛ/	542	1829	540	1813	565	1776	577	1710	551	1655
had /æ/	667	1741	642	1781	644	1769	655	1719	649	1646
hod /ɑ/	742	1132	758	1133	755	1142	758	1201	735	1307
who'd /u/	379	1242	371	1206	352	1179	348	1169	331	1212
hood /ʊ/	450	1152	457	1148	459	1178	476	1261	464	1396

Continued

APPENDIX B. *Continued*

	20%		35%		50%		65%		80%	
	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2
hoed /o/	521	1116	497	1081	453	1032	404	987	372	1013
hawed /ɔ/	645	959	647	952	636	950	624	983	605	1102
hide /aɪ/	772	1246	766	1304	722	1454	592	1687	458	1896
hoyd /oɪ/	509	832	511	884	537	1155	475	1579	386	1845
howed /aʊ/	786	1388	766	1309	708	1162	610	988	527	902
OH Females (GP)										
heed /i/	369	2822	353	2838	346	2853	333	2858	320	2834
hid /ɪ/	462	2493	477	2382	537	2224	557	2079	568	2001
heyd /e/	586	2505	530	2575	476	2657	403	2721	368	2761
head /ɛ/	682	2327	689	2234	710	2131	722	2013	693	1971
had /æ/	874	2227	860	2212	866	2149	881	2028	846	1943
hod /ɑ/	959	1326	951	1325	932	1333	935	1419	903	1607
who'd /u/	410	1551	408	1509	385	1461	364	1411	346	1437
hood /ʊ/	500	1407	507	1431	535	1499	548	1621	542	1792
hoed /o/	679	1403	588	1345	508	1276	453	1217	401	1205
hawed /ɔ/	839	1174	834	1167	833	1166	829	1240	796	1389
hide /aɪ/	966	1425	960	1536	895	1833	708	2216	517	2524
hoyd /oɪ/	591	968	577	1060	606	1493	566	2124	434	2486
howed /aʊ/	1010	1675	965	1500	864	1300	693	1108	535	972
WI Boys										
heed /i/	311	3155	312	3165	312	3170	322	3139	340	3065
hid /ɪ/	551	2633	552	2603	551	2569	556	2539	549	2505
heyd /e/	559	2745	522	2839	493	2897	462	2939	447	2943
head /ɛ/	872	2307	870	2288	844	2318	796	2324	746	2337
had /æ/	866	2454	905	2380	972	2234	1005	2075	958	2108
hod /ɑ/	1092	1588	1089	1596	1086	1632	1047	1724	971	1934
who'd /u/	410	1187	400	1160	395	1141	397	1141	399	1252
hood /ʊ/	616	1471	628	1501	618	1584	605	1757	588	1966
hoed /o/	644	1206	580	1119	525	1053	488	1032	456	1125
hawed /ɔ/	936	1294	947	1295	961	1348	972	1493	924	1769
hide /aɪ/	1093	1719	1065	1824	949	2122	758	2460	589	2705
hoyd /oɪ/	580	1049	596	1207	601	1677	535	2383	478	2740
howed /aʊ/	1096	1747	1035	1601	915	1397	738	1176	584	1128
WI Girls										
heed /i/	408	3297	401	3291	398	3322	401	3274	397	3202
hid /ɪ/	606	2695	608	2668	615	2653	600	2619	578	2577
heyd /e/	609	2922	556	3030	502	3116	479	3178	470	3149
head /ɛ/	939	2400	926	2401	909	2416	865	2436	770	2447
had /æ/	943	2560	978	2471	1050	2309	1074	2186	1007	2185
hod /a/	1111	1638	1124	1664	1113	1722	1092	1833	1014	1994
who'd /u/	468	1302	455	1258	438	1225	428	1208	431	1337
hood /ʊ/	698	1564	706	1639	692	1792	676	2000	625	2194

Continued

APPENDIX B. *Continued*

	20%		35%		50%		65%		80%	
	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2
hoed /o/	703	1244	643	1170	586	1105	534	1081	510	1197
hawed /ɔ/	1008	1401	1018	1405	1027	1485	1028	1682	963	1966
hide /aɪ/	1151	1889	1086	2070	921	2370	695	2756	559	2956
hoyd /oɪ/	636	1063	660	1272	653	1921	540	2612	447	2937
howed /aʊ/	1156	1930	1090	1781	985	1531	778	1301	618	1220
WI Males (P)										
heed /i/	298	2291	293	2312	283	2321	283	2316	284	2283
hid /ɪ/	421	1922	441	1888	467	1820	488	1768	479	1733
heyd /e/	460	2033	432	2091	412	2135	390	2155	372	2154
head /ɛ/	625	1732	632	1695	642	1666	632	1664	589	1667
had /æ/	640	1850	651	1833	683	1770	710	1675	690	1620
hod /ɑ/	806	1303	813	1306	810	1324	794	1362	744	1458
who'd /u/	346	962	342	939	330	934	328	962	334	1082
hood /ʊ/	454	1083	457	1101	477	1169	498	1301	483	1473
hoed /o/	511	932	471	881	444	843	425	854	408	984
hawed /ɔ/	675	1029	692	1039	707	1080	724	1162	703	1342
hide /aɪ/	789	1361	767	1458	696	1623	585	1808	470	1949
hoyd /oɪ/	492	855	520	982	533	1293	479	1682	416	1905
howed /aʊ/	781	1244	749	1170	664	1067	566	968	501	995
WI Females (P)										
heed /i/	317	2722	313	2732	320	2740	331	2733	342	2691
hid /ɪ/	503	2359	511	2288	544	2178	548	2108	527	2066
heyd /e/	459	2537	420	2579	397	2630	383	2657	366	2638
head /ɛ/	774	2070	773	2015	762	1987	719	1992	667	1997
had /æ/	764	2238	793	2203	852	2039	885	1868	845	1829
hod /ɑ/	996	1464	987	1470	972	1498	941	1562	872	1703
who'd /u/	404	1018	392	998	379	1002	377	1027	360	1154
hood /ʊ/	542	1207	539	1276	549	1397	564	1584	541	1788
hoed /o/	590	1037	527	973	471	934	435	932	413	1057
hawed /ɔ/	856	1186	863	1207	866	1277	872	1411	830	1638
hide /aɪ/	979	1590	919	1721	794	1982	613	2284	452	2444
hoyd /oɪ/	567	968	571	1129	572	1590	505	2162	405	2396
howed /aʊ/	974	1515	913	1415	799	1256	640	1102	539	1079
WI Males (GP)										
heed /i/	288	2198	277	2231	270	2225	267	2212	270	2173
hid /ɪ/	376	1928	409	1879	450	1804	466	1740	460	1691
heyd /e/	389	2057	380	2098	377	2123	354	2147	354	2120
head /ɛ/	529	1801	569	1765	588	1707	588	1655	556	1624
had /æ/	589	1848	612	1820	619	1785	640	1689	652	1607
hod /ɑ/	785	1279	781	1298	784	1307	768	1336	715	1432
who'd /u/	328	800	321	782	312	797	313	831	316	987
hood /ʊ/	426	1034	459	1054	475	1148	481	1301	465	1453

Continued

APPENDIX B. *Continued*

	20%		35%		50%		65%		80%	
	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2
hoed /o/	461	835	438	812	422	797	396	796	374	928
hawed /ɔ/	681	1026	683	1052	670	1067	675	1128	664	1294
hide /aɪ/	757	1388	710	1515	617	1682	501	1872	412	1982
hoyd /oɪ/	497	915	523	1069	510	1409	426	1743	369	1893
howed /aʊ/	750	1174	684	1092	591	982	506	900	432	941
WI Females (GP)										
heed /i/	318	2759	309	2791	314	2803	324	2785	339	2767
hid /ɪ/	439	2493	465	2402	501	2250	535	2093	548	1999
heyd /e/	443	2640	428	2678	408	2722	380	2724	360	2742
head /ɛ/	579	2413	618	2309	655	2151	702	2012	675	1962
had /æ/	678	2441	686	2400	726	2291	794	2084	823	1901
hod /ɑ/	968	1442	978	1451	979	1490	956	1543	893	1648
who'd /u/	363	936	359	933	360	929	358	947	350	1130
hood /ʊ/	473	1157	504	1207	538	1322	550	1512	548	1745
hoed /o/	493	910	471	871	441	840	418	833	403	942
hawed /ɔ/	775	1103	770	1136	791	1185	815	1315	793	1529
hide /aɪ/	969	1613	927	1802	803	2058	634	2355	466	2536
hoyd /oɪ/	577	1026	595	1187	615	1648	498	2173	421	2439
howed /aʊ/	912	1321	847	1249	741	1128	605	1026	495	1024
NC Boys										
heed /i/	451	2960	424	3009	389	3028	369	3031	370	2991
hid /ɪ/	473	2748	473	2685	494	2587	487	2477	496	2379
heyd /e/	696	2297	590	2437	515	2607	452	2747	429	2808
head /ɛ/	599	2449	590	2463	584	2428	587	2355	597	2283
had /æ/	922	2199	917	2228	909	2231	889	2184	854	2149
hod /ɑ/	907	1244	900	1231	900	1262	899	1407	851	1675
who'd /u/	478	2011	462	1988	437	1917	406	1822	391	1742
hood /ʊ/	503	1761	491	1759	488	1791	483	1887	492	1987
hoed /o/	670	1605	599	1580	490	1532	451	1461	421	1423
hawed /ɔ/	900	1244	881	1222	855	1184	818	1197	748	1314
hide /aɪ/	1055	1517	1061	1537	1037	1623	952	1853	773	2151
hoyd /oɪ/	501	884	492	932	500	1215	491	1873	441	2439
howed /aʊ/	993	2020	996	1892	974	1656	868	1374	678	1170
NC Girls										
heed /i/	503	3126	478	3169	469	3189	466	3209	469	3164
hid /ɪ/	525	2837	525	2803	538	2714	582	2601	609	2498
heyd /e/	800	2542	716	2657	595	2827	517	2940	459	3031
head /ɛ/	773	2546	764	2563	744	2532	725	2512	698	2461
had /æ/	1084	2221	1082	2213	1075	2189	1052	2164	967	2209
hod /ɑ/	944	1328	942	1329	953	1401	943	1560	877	1874
who'd /u/	511	2035	493	2020	476	1959	450	1877	446	1783
hood /ʊ/	564	1881	558	1905	570	1959	575	2050	583	2183

Continued

APPENDIX B. *Continued*

	20%		35%		50%		65%		80%	
	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2
hoed /o/	759	1693	685	1671	608	1600	530	1508	478	1447
hawed /ɔ/	926	1274	919	1258	903	1276	894	1353	839	1532
hide /aɪ/	1131	1583	1107	1640	1081	1808	962	2157	751	2489
hoyd /oɪ/	532	934	536	1052	584	1531	563	2257	465	2750
howed /aʊ/	1115	1982	1092	1830	1019	1577	894	1327	710	1152
NC Males (P)										
heed /i/	340	2235	315	2295	290	2323	280	2336	261	2361
hid /ɪ/	348	2193	356	2188	375	2107	431	1958	488	1815
heyd /e/	560	1831	489	1947	416	2072	365	2178	329	2239
head /ɛ/	456	2018	440	2052	441	2031	497	1917	542	1779
had /æ/	664	1792	631	1854	612	1870	629	1811	652	1716
hod /ɑ/	722	1091	718	1079	730	1101	734	1156	711	1302
who'd /u/	391	1537	376	1528	360	1509	340	1488	318	1485
hood /ʊ/	406	1386	406	1381	409	1401	424	1451	442	1525
hoed /o/	572	1274	505	1223	439	1173	390	1126	359	1129
hawed /ɔ/	735	1106	704	1048	665	982	597	921	536	925
hide /aɪ/	829	1418	828	1423	817	1455	783	1517	714	1606
hoyd /oɪ/	462	755	437	732	454	873	471	1275	424	1770
howed /aʊ/	746	1604	733	1563	730	1389	689	1147	606	1006
NC Females (P)										
heed /i/	399	2661	388	2700	373	2749	368	2768	354	2764
hid /ɪ/	424	2600	425	2527	488	2341	573	2130	590	2021
heyd /e/	718	2233	624	2371	494	2479	431	2586	384	2650
head /ɛ/	571	2439	549	2443	579	2336	661	2147	683	2023
had /æ/	850	2192	804	2257	801	2229	827	2088	837	1931
hod /ɑ/	893	1232	898	1238	893	1268	880	1343	853	1539
who'd /u/	448	1891	433	1869	406	1843	397	1802	389	1766
hood /ʊ/	455	1683	457	1683	473	1702	506	1741	510	1823
hoed /o/	743	1594	651	1576	556	1549	451	1485	405	1445
hawed /ɔ/	908	1247	872	1199	844	1160	801	1119	733	1134
hide /aɪ/	1025	1572	1010	1577	1001	1612	959	1695	864	1857
hoyd /oɪ/	483	833	466	832	520	1067	541	1583	480	2057
howed /aʊ/	925	1932	917	1841	929	1592	873	1305	766	1147
NC Males (GP)										
heed /i/	346	2159	313	2219	302	2270	287	2294	280	2280
hid /ɪ/	368	2097	359	2113	382	2077	436	1959	484	1787
heyd /e/	566	1790	496	1932	417	2038	372	2117	331	2141
head /ɛ/	481	1985	447	2037	444	2044	477	1963	523	1793
had /æ/	609	1815	573	1880	558	1908	583	1841	606	1721
hod /ɑ/	690	1059	683	1049	688	1052	685	1092	669	1199
who'd /u/	412	1498	378	1470	350	1428	330	1385	318	1405
hood /ʊ/	413	1306	407	1285	423	1292	448	1332	466	1437

Continued

APPENDIX B. *Continued*

	20%		35%		50%		65%		80%	
	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2
hoed /o/	557	1153	496	1073	434	1008	381	967	352	996
hawed /ɔ/	699	1106	664	1050	621	1002	569	959	514	986
hide /aɪ/	794	1474	792	1479	782	1489	763	1507	719	1520
hoyd /oɪ/	515	845	487	811	504	902	533	1194	512	1542
howed /aʊ/	697	1652	694	1603	692	1388	658	1193	621	1181
NC Females (GP)										
heed /i/	418	2642	400	2674	363	2723	324	2752	312	2743
hid /ɪ/	450	2652	432	2663	425	2593	507	2435	562	2222
heyd /e/	684	2224	602	2345	489	2487	416	2594	377	2660
head /ɛ/	524	2529	487	2568	502	2564	543	2436	616	2246
had /æ/	769	2299	705	2390	675	2436	705	2360	750	2190
hod /ɑ/	926	1298	911	1283	895	1286	886	1315	882	1459
who'd /u/	470	1832	444	1810	427	1759	405	1706	381	1679
hood /ʊ/	454	1599	458	1579	463	1569	505	1595	538	1717
hoed /o/	691	1529	605	1461	537	1384	459	1287	410	1221
hawed /ɔ/	935	1343	895	1297	808	1234	732	1167	595	1097
hide /aɪ/	1073	1748	1043	1732	1029	1753	991	1811	912	1944
hoyd /oɪ/	578	1028	522	937	543	1023	577	1564	549	2092
howed /aʊ/	935	2074	910	1978	924	1718	851	1433	760	1266