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6 The Influence of Age on Estimating Sound Change Acoustically From Longitudinal Data

Ulrich Reubold and Jonathan Harrington¹

1. Introduction

There is now abundant evidence that beyond the critical age, adult speech is subject to numerous changes over the lifespan. This chapter is concerned with how longitudinal changes of a sociophonetic nature (e.g., Conn and Horesh 2002; Sankoff and Blondeau 2007) can be distinguished acoustically from changes due to biological aging of the vocal tract (Linville 2001).

1.1 Changes Related to Biological Aging

Comparisons of age cohorts of adults² have shown mainly an age-related decrease of the frequency of the first formant (F1), and this has been hypothesized to be related to changes in the length and/or volume of the vocal tract (Linville and Fisher 1985; Xue and Hao 2003). Longitudinal studies (Harrington 2006; Harrington, Palethorpe and Watson 2007) confirmed that F1 typically decreased with increasing age. In Reubold, Harrington and Kleber (2010), the mean fundamental frequency (f0) and mean F1 were found to co-vary over a 50-year period for the British Queen Elizabeth II (linear decrease of both parameters) and for the broadcaster Alistair Cooke (a decrease of both parameters followed by a late, very pronounced increase). Our explanation was that f0 is likely to change for physiological reasons (Linville 2001; Gugatschka et al. 2010) but that F1 may track f0 for auditory reasons. This is because the distance between f0 and F1 has been shown to be a cue to vowel height (Traunmüller 1981), at least when f0 and F1 are close enough in frequency to be perceptually integrated (Chistovich and Lublinskaya 1979). That is, the speakers may be recalibrating their F1 in relation to f0 in order to maintain a perceptually constant vowel height over the lifespan. A subsequent analysis in Reubold and Harrington (2015) showed for Cooke that this relationship between f0 and F1 over the lifespan occurs predominantly in phonetically high vowels (in which f0 and F1 are close together in frequency), whereas the relationship was less clear in mid vowels. In phonetically low vowels by contrast, there were F1 changes that were not related to longitudinal shifts in f0 but mainly characterized by increasing centralization at an older age (see Rastatter and Jacques 1990).

An unresolved issue and our first aim, addressed in section 2, is whether this vowel-dependent interaction between f0 and F1 with increasing age is also evident in speakers other than Cooke. We addressed this issue by analyzing additional longitudinal data from two females, the British Queen Elizabeth II and Dagmar Berghoff, a German newsreader.

1.2 Longitudinal Sociophonetic Change

The sociophonetic change that will be analyzed in the third section of this chapter is a reversion in later life to an accent that was produced in young adulthood. Our earlier studies have shown an incremental change between variants from younger to older age (e.g., Harrington, Palethorpe, and Watson 2000a, 2000b, 2005; Harrington 2006, 2007). However, other longitudinal studies have found sociophonetic changes in adults to varying degrees (e.g., MacKenzie and Sankoff 2010). Bowie (2015) showed that the majority of his speakers deviate from an otherwise generally stable sociophonetic variable at unpredictable points in time, and also revert to the formerly preferred variant. A non-linear pattern of change away from earlier acquired innovative to obsolescent sociolinguistic variants at higher ages has been observed in various studies (e.g., Sankoff and Wagner 2006; Wagner and Sankoff 2011; MacKenzie forthcoming).

The starting point for the present investigation is an analysis in Reubold and Harrington (2015) of the British journalist Alistair Cooke (20 November 1908–30 March 2004) who had immigrated to the USA in his early adulthood. An American accent colored his vowels, but he showed evidence of change toward the Received Pronunciation (RP) accent in later life that we had assumed must have characterized his accent prior to emigration. We concluded that this would suggest a *reversion* of his accent toward one acquired in England in Cooke's childhood/youth before he immigrated to the US.

However, our results were based on an assumption that the speaker really was an RP speaker prior to immigrating to the US, which is decisive for the claim of an accent reversion instead of a late acquisition of RP-like vowels. Yet, in Reubold and Harrington (2015), there was only anecdotal evidence (Clarke 2000: 17) that Cooke-who was born and raised in Lancashirereplaced a Northern English accent with RP as a 12- to-13-year-old schoolboy. An additional recording of Cooke analyzed in this paper when he was a 25-year-old visiting student at Yale allows us to test our assumption of young Cooke's accent being RP at that time.

A second unresolved issue is the nature of the change toward RP-like vowels found in Reubold and Harrington (2015), especially BATH backing, which seemed to have occurred abruptly sometime during the period between two recordings made at ages 61 and 72. This large 11-year gap did not allow us to investigate whether there were either intermediate vowel productions or whether /æ/ and /a/ were produced word-specifically in BATH

words during that period. Since then, we have gained access to recordings that will allow us to test more precisely whether the change was phonetically gradual (instead of being abrupt) and/or word-specific and whether lexical frequency plays a role in the advancement of that change (see, e.g., Bybee 2002; Hay and Foulkes 2016; Hay, Pierrehumbert, Walker and LaShell 2015; Lin, Beddor and Coetzee 2014).

2. Age-Related Changes to the First Formant Frequency

The focus of the analysis is on longitudinal data from Alistair Cooke (1908–2004) and two female speakers: Queen Elizabeth II (born 1926) and Dagmar Berghoff (born 1943), a German newsreader and trained actress. Given that f0 and F1 are usually closer in women, and taking into account the results of studies showing a decrease of f0 in females (Baken 2005; Nishio and Niimi 2008), we tested whether:

- I.a): F1 decreases in the Queen and Berghoff with increasing age in high vowels.
- I.b): F1 decreases in the Queen and Berghoff with increasing age in mid vowels.
- I.c): F1 in low vowels does not interact with changes to f0, but it may decrease in very old age.

2.1 Method Ot for distribution

Materials

For all three speakers, we selected materials from public broadcasting archives that allowed us to control for constant speech genres within the speakers. The materials included *Letter from America*, Alistair Cooke's weekly BBC radio broadcast about American life, history and politics, addressing a mostly British audience; Queen Elizabeth II's annual *Christmas message* to the British Empire and later the Commonwealth, in which she reflects primarily on events that had happened in the current year; and the 15-minute daily main bulletin of German public service TV newscast *Tagesschau*, presented by Dagmar Berghoff. All three types of broadcast consist of read speech.

For Cooke, we included data from Reubold et al. (2010) from 47 broadcasts of *Letter from America* (mean duration: 13.5 minutes), covering the ages between 38 to 95 years.³ We also present a subset of these data that had been labeled phonetically (Reubold and Harrington 2015).

For Queen Elizabeth II, we analyzed 28 Christmas messages⁴ (mean duration: 5.1 minutes) that were available and that had been phonetically labeled at the time of writing earlier studies (Harrington et al. 2000a, 2000b, 2005; Harrington 2006, 2007). They cover the age range of 26 to 76 years.

For Berghoff, we analyzed 34 recordings from Tagesschau (news broadcast daily at 20:00 CET; all recordings were taken from the main 15-minute bulletins), from 1976-79, 1980-85, 1988-89, 1991-96, 1998 and 1999. These recordings were put together by Benina Knothe, University of Münster. Additionally, Knothe re-recorded Berghoff in 2013, reading texts originally spoken in one broadcast each of 1976, 1980 and 1999. Therefore, the coverage includes the age range 33 to 70 years.

Acoustic Data Preparation and Analysis

The sampling frequency for the sound files of Queen Elizabeth II and Dagmar Berghoff were 16 kHz and 20 kHz for Cooke. Formant frequencies and synchronized f0 were calculated with a frame shift of 5 ms and a window length of 20 ms. Obvious errors in the first three formants were manually corrected by phonetically trained student assistants.

The voiced frames that were analyzed include all of those 5 ms intervals that the f0 tracker identified as voiced. We calculated the arithmetical mean of all f0 and formant data per year of recording (henceforth usually presented as age of the speaker in years), following the procedure in Reubold et al. (2010).

Vowel segmentation and labeling for Cooke and Berghoff (the data from Queen Elizabeth II had been segmented and labeled earlier) were carried out using forced-alignment (WebMAuS, Kisler, Schiel, and Sloetjes 2012) combined with available orthographic transcripts. This method was applied to a subset of Cooke's data, i.e. to one recording each from 1951, 1960, 1970, 1981, 1993 and 2004, and to all the Tageschau broadcasts by Berghoff. For all three speakers, we analyzed only vowels in syllables bearing primary lexical stress of nuclear accented words. The total numbers of vowels analyzed were 2,229 for Cooke, 2,570 for the Queen and 3,451 for Berghoff.

To observe differences in trends of change over time to different vowel heights, we averaged over three vowel height groups ('High,' i.e. all close and half-close vowels, irrespective of backness or roundedness; 'Mid,' i.e. all close-mid and open-mid vowels; 'Low', i.e. near-open and open vowels), following the procedure in Reubold and Harrington (2015). We excluded those vowels from the Queen's data that were shown to be subject to a longitudinal phonetic change of vowel quality including vowels from the lexical set TRAP (which was shown to have lowered phonetically in Harrington 2007) and vowels from the lexical sets LOT, THOUGHT, BATH, and DRESS in Cooke (which had also been shown to change phonetically in Reubold and Harrington 2015). We did not exclude any vowels from Berghoff, as we did not expect any sociophonetically relevant variation in her (Northern) Standard German.

We applied linear or (second- or third-order) polynomial regression with the logarithm of f0 and F1 as dependent variables and age as the regressor in order to determine any age-related changes to these parameters. We also

automatically estimated speech rate (in syllables /second) in Berghoff's data (based on an estimation of syllable nuclei as a function of intensity and probability of voicing following De Jong and Wempe 2009) in order to test whether speech rate varied as a function of age and whether speech rate differences co-varied with clarity as measured by vowel space expansion (Lindblom 1990; Wright 2004). More specifically, we calculated separately per recording the F1-distances of /i, u, a/ to Berghoff's F1 averaged across all vowels in order to determine the degree to which they were phonetically peripheral.

2.2 Results

Figure 6.1 shows the fundamental and first formant frequency on a logarithmic Hz-scale for all voiced frames of the three longitudinal data sets. The data show a decrease in both f0 and F1 with increasing age for the Queen (Figure 6.1a); for Cooke (Figure 6.1b): these parameters decrease up to the age of 87 years and increase thereafter at the same rate. The new data for Berghoff (Figure 6.1c) is, however, quite different: There is no consistent age-related change in F1, and f0 stays about the same until the age of 50 years, after which f0 decreases.

The data in Figure 6.1e show that the F1-change in Cooke's data to high vowels is U-shaped and patterns with his data pooled across vowel categories in Figure 6.1b. As Figure 6.1e illustrates (and as demonstrated in Reubold and Harrington 2015), F1 follows a \cap -shaped trend for low vowels, while there was no significant trend with increasing age for mid vowels.

As far as the Queen is concerned (Figure 6.1d), F1 decreased linearly with increasing age in both high (*adjusted* $R^2 = 0.40$; F[1,27] = 20.0, p < 0.001) and in mid (*adjusted* $R^2 = 0.86$; F[1,13] = 84.3, p < 0.001) vowels, while in contrast to Cooke, there was no age-related change to F1 in low vowels. Figure 6.1f shows that there are scarcely any changes to F1 in Berghoff's mid and high vowels. There is a linearly rising trend in F1 of low vowels (*adjusted* $R^2 = 0.31$; F[1,19] = 10.0, p < 0.01), at least when the data point at age 70 is included; however, the slight rise between the ages of 33 and 56 failed to reach significance F[1,18] = 3.9, n.s.).

The left column of Figure 6.2 presents Berghoff's vowel height dispersion as a function of age. The data is best fit with a third order polynomial (*adjusted* $R^2 = 0.46$; F[3,29] = 10.0, p < 0.001). The same was found for speech rate (middle column of Figure 6.2: *adjusted* $R^2 = 0.50$; F[3,29] = 11.9, p < 0.001). Moreover, this trajectory's shape varies inversely with the measure of vowel height dispersion: both parameters were indeed negatively correlated (Figure 6.2 right, solid line; linear regression: $R^2 = 0.22$, F[1,31] = 8.9, p < 0.01). Considering only those materials from 1976, 1980 and 1999 that were re-recorded in 2013, we also found a negative correlation between vowel height dispersion and speech rate ($R^2 = 0.64$, F[1,4] = 10.1, p < 0.05; gray dashed line in rightmost column of Figure 6.2).

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Figure 6.1 The data in the top row shows f0 (open circles) and F1 (filled circles) as a function of age for the 3 speakers with superimposed significant regressions. Each data point is an average across voiced frames. The bottom row presents F1 data as set out above, but separated by vowel quality. Each data point is an average across measurements at the vowel's temporal midpoint. Panels a) and b) are adapted from Reubold et al. (2010), and panel e) is reproduced with permission from Reubold et al. (2015, Figure 6.2).



Figure 6.2 Berghoff's Vowel Height Dispersion measure (left) and Speech Rate (middle) as a function of biological age, and Vowel Height Dispersion as a function of Speech Rate (right). Regression curves/lines are superimposed. The data points represented by an extra diamond symbol were obtained from the re-recorded texts.

2.3 Discussion

For Alistair Cooke and Queen Elizabeth II, F1 for high vowels and the fundamental frequency show very similar patterns of change with increasing age, with an age-related decrease (and then subsequent increase in Cooke) on both parameters in both speakers. A very similar decrease was also found for F1 in Queen Elizabeth's but not Cooke's mid vowels. This finding is nevertheless predicted from the model by which F1 is adjusted if it is perceptually close to f0. This is because F1 of mid vowels is closer to f0 in the Queen than in Cooke (by approximately 0.5 Bark). However, Berghoff's data are quite different: although there was an age-related decrease in f0 after the age of 50 years, F1 did not change in high and mid vowels, despite the relative proximity of F1 and f0.

Whereas Cooke's F1 in low vowels decreased in old age, suggesting an age-related centralization (Rastatter and Jacques 1990), we did not find any change in low vowels' F1 in the Queen and, surprisingly, there was an increase of F1 with increasing age in Berghoff's low vowels, suggesting a wider mouth-opening in later years. This may be related to a stylistic variation: Speech tempo and the vertical expansion of Berghoff's vowel space co-varied with increasing age, with an increase in speech tempo followed by a decrease, and an inverse pattern for vertical vowel space expansion. An age-related decrease of speech tempo (see also Duchin and Mysak 1987) can be associated with slower movements of the speech organs (Linville 2001: 60–62); the age-related centralization found in Rastatter and Jacques (1990) or in Cooke's data may also be another consequence of a reduction in articulatory velocity. However, Berghoff's vowel height was acoustically compressed with increasing speech tempo (see Miller 1981), and at least the initial increase of speech tempo is unlikely to have been caused by biological age. It is possible that this change in speech tempo may instead be related to other factors like varying time-pressure in the Tagesschau newscasts. The possible role of time-pressure is especially evident in the data obtained from re-recordings at age 70, which were conducted without any time pressure; under these circumstances, we observed the slowest speech rate and the maximal vertical expansion of the vowel space (instead of an age-relatedly compressed vowel space).

3. Accent Reversion in Alistair Cooke

The focus of the second part of the study is on accent changes over Alistair Cooke's lifespan in vowels of the lexical set BATH. There were three hypotheses:

II.a) Cooke's BATH vowels are acoustically closer to START vowels at age 25 years, and also at ages 72–95 years, but closer to TRAP at ages 42–61 years.

- II.b) Cooke's BATH vowels are intermediate between TRAP and START during the change, and move toward START incrementally.
- II.c) The advancement of the change in Cooke's BATH vowels will be wordspecific and dependent on the lexical frequency of the words.

We additionally explored the effectiveness of the log. Euclidean distance ratio (Harrington 2006), which should normalize out any effect due to vocal aging but preserve phonetic differences due to the accent change.

3.1 Method

We added to the recordings of *Letter from America* analyzed in Reubold and Harrington (2015) two new materials. Firstly, an interview with the 25-year-old Cooke that had originally been recorded onto disc in 1934 at Harvard University and subsequently converted into wav-format by the Archive of Folk Culture (Hall, Howard, McLean, Vallier, and Gersten 2009). This recording was of rather poor audio quality and had to be pre-processed with noise-reduction tools in *audacity* (Audacity Developer Team 2015). After removing the contributions from the (American) interviewer, nine minutes of speech data by Cooke remained, which were annotated orthographically.

Secondly, we included 14 additional *Letter from America* broadcasts over the period 1975–1977: one in May 1975, 12 from 1976 (one in each month) and one from July 1977. These were included because we impressionistically judged, after listening to audio recordings from 1972 to 1981, the change in Cooke's BATH vowels from $/\alpha$ / to /d/ to have taken place during this period. The BBC has only recently published these recordings of Cooke's broadcasts from the 1970s (along with orthographic transcriptions).

We resampled both new sets of audio data to 20 kHz to obtain consistency with the 1951–2004 *Letter from America* data. The data were automatically segmented and labeled. Any required manual corrections were made to Cooke's vowels from the lexical sets BATH, TRAP, START and PALM (the latter two are henceforth pooled and referred to as START⁵). Only vowel nuclei of stressed syllables in nuclear-accented words were analyzed. This resulted in 8 BATH, 14 START and 48 TRAP words from 1934, and in 162 BATH, 270 START and 725 TRAP words from 1975–77. This uneven distribution of these three categories is very similar to that reported in Reubold and Harrington (2015) for the 1951–2004 data.

The first two formant frequencies were manually corrected in these vowels, if necessary. We quantified the relative distance of BATH to TRAP and to START from (1):

$$d_{i,j} = \log(E_{\text{TRAP},i,j}/E_{\text{START},i,j}) = \log(E_{\text{TRAP},i,j}) - \log(E_{\text{START},i,j})$$
(1)

in which $E_{TRAP.i.j}$ and $E_{START.i.j}$ are the Euclidean distances from a given BATH token to the mean positions of TRAP and to the mean position of START

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respectively on acoustic parameter *i* and in broadcast *j* and in which $d_{i,j}$ is the logarithm of the ratio between the two. There were three possible parameters: *i* = F1, F2, and F1 × F2 (i.e. points in a two-dimensional space) always extracted at the temporal midpoint of the vowel. For example, for *i* = F1, $E_{TRAP.F1,j}$ was the mean of F1 across all TRAP tokens in broadcast *j* and there was one $d_{.F1,j}$ value per BATH vowel that had been produced in the same broadcast.⁶

When $d_{i,i} < 0$, a given BATH vowel is closer to TRAP and closer to START for $d_{i,j} > 0$, and equidistant between TRAP and START for $d_{i,j} = 0$.

To test for possible effects of lexical frequency, we used so-called Zipf values, i.e. standardized measures of word frequencies, taken from SUBTLEX-UK, a database that aims at representative frequency measures of spoken language, and which is based on subtitles by the BBC (Van Heuven, Mandera, Keuleers, and Brysbaert 2014).⁷ The Zipf values, calculated as log_{10} (frequency per billion words), extend theoretically between 0 and 9, but realistically between 1 (very low frequency words) and 7 (very frequent words like 'and,' 'for,' 'have,' 'you'). We specified a Zipf value of 4 as separating roughly low-frequency from high-frequency words.

We used regression techniques and linear mixed models to estimate the dependency of the relative positions of the BATH vowels between TRAP and START (in terms of the log. Euclidean distance ratios) on both age and word frequency and the interaction between the two.

3.2 Results of for distribution

Impressionistically, Cooke spoke RP in 1934 in a variety that is close to upper-crust or U-RP (Wells 1982), as it shares many of its typical aspects such as tapped intervocalic rhotics, a very retracted GOOSE and other properties that have been lost in today's mainstream RP (and even in the Queen's English; see Harrington et al. 2000a, 2000b, 2005; Harrington 2006, 2007). As far as BATH vowels are concerned, we perceived consistently RP-like /a/. In the recordings made between 1951 and 1975, BATH vowels were consistently clear cases of $/\alpha$ /, and again of /a/ from 1977 onwards (with the exception of the second vowel in 'Iraq'). However, we perceived many BATH tokens as being intermediate between $/\alpha$ / and /a/ during the 1975–1977 period.

Age-Related vs. Sociophonetic Changes to Formants

We had predicted a change in BATH vowels from /a/ at age 25 to /æ/ at ages 42, 51 and 61 years, and back to /a/ at ages 72, 84, and 95 years. F2, which is correlated with perceived vowel backness, was found to vary with the passage of time between /æ/ and /a/, with lower values at ages 25, 72, 84 and 95 years and raised values at ages 42, 51 and 61 years, resulting in a \cap -shaped trajectory over time (cubic regression with *adjusted* $R^2 = 0.86$, F[3,40] = 85.7, p < 0.001, see Figure 6.3a). On the other hand, F1 also varied to about the same degree



Figure 6.3 Left (a): F1 and F2 of all BATH vowels as a function of biological age, presented over the full 70-year period of observation. Best-fit regression curves are superimposed together with the trajectories for START (gray, dashed) and TRAP (gray, dotted)). Right (b): Centroids of the distributions of BATH (B, black), TRAP (T) and START (S, gray) vowels for the ages 25, 42, 51, 61, 72, 84 and 95, in the F1 × F2 plane. Each data point is an average at a particular age.

(of approximately 2 Bark) with age, but had a falling-rising-falling trajectory (third order polynomial with *adjusted* $R^2 = 0.63$, F[3,40] = 25.2, p < 0.001). However, this trajectory patterned more closely with F1 in TRAP and START, especially as far as the decrease of F1 beyond the age of approximately 80 years is concerned. A possible exception from the general trend in F1 of TRAP and START is at ages 42 and 51 years, at which F1 is somewhat lower in BATH.

Figure 6.3b shows the two anchor vowels TRAP and START and the BATH vowel in relation to these. There was obviously much variation in F1 in all three vowel types; the variation in BATH in relation to TRAP and START (which show a minimal change in F2 with increasing age) was principally restricted to the front-back dimension (in terms of F2).

Bath in Relation to TRAP and START—Euclidean Distance Ratios

The Euclidean distance ratios measured in F1 only (d_{F1}) varied around 0 and were not affected by age (F[3,40] = 2.9, n.s.). A multiple regression with $d_{F1 \times F2}$ as the dependent variable and with two regressors, d_{F2} and d_{F1} , showed a strong correlation of $d_{F1 \times F2}$ with d_{F2} (*adjusted* R^2 = 0.86; t[42] = 16.3, p < 0.001), but not with d_{F1} (t[42] = 0.6, n.s.). This shows that the changes in F1 scarcely contributed to shifts with the passage of time in the



BATH rel. to TRAP and START

Figure 6.4 Euclidean distance ratios (calculated in the F2-dimension) as a function of biological age. Positive and negative values are for BATH tokens closer to START and TRAP respectively.

relative distances of BATH between TRAP and START, whereas most of this shift was caused by F2. We therefore opted for analyzing henceforth only d_{F2} .

Figure 6.4 shows the U-shaped trajectory of d_{F2} . Euclidean Distance Ratios were above 0 (i.e. BATH was nearer to START) at the age of 25 years, and from 72 years onwards, whereas they were negative (i.e. nearer to TRAP) at Cooke's middle years (42, 51 and 61 years). There were four exceptions to this at age 95, at which vowels in four tokens of the word 'Iraq' are also impressionistically clear cases of $/\alpha$. The best fitting regression (excluding these four 'Iraq'-tokens) was a third-order polynomial (*adjusted* $R^2 = 0.71$, F[3,40] = 36.7, p < 0.001).

Figure 6.5a presents d_{F2} of all vowel tokens of all BATH word types during the period 1975–77 as a function of *time of recording*. A third order



Figure 6.5 Euclidean distance ratios as a function of time of broadcast for all BATH tokens (left, *a*) and for 'after' only (right, *b*).

polynomial with *adjusted* $R^2 = 0.11$, F[3,155] = 7.3, p < 0.001 confirms an increase of d_{F2} during that period. Figure 6.5b shows BATH vowels extracted only from the word 'after' for the years 1975–77. The best-fit regression was linearly increasing ($R^2 = 0.23$, F[1,35] = 11.7, p < 0.01).

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Lexical Frequency

According to hypothesis II.c), the advancement of the change in BATH vowels should be word-specific, with more frequent words behaving differently than less frequent ones.

Figure 6.6c shows that high-frequency words were more backed during the period of change, whereas low-frequency words were nearer to the (front) TRAP anchors. d_{F2} and lexical frequencies were positively correlated ($R^2 = 0.16$, F[1,160] = 30.5, p < 0.001).

In order to analyze whether lexical frequency interacted with time, we conducted a mixed-effects regression model with d_{F2} as dependent variable, and with both *time* (in months, i.e. 1 . . . 27 corresponding to the monthly intervals from May 1975 to July 1977) and *lexical frequency* (the Zipf_{UK}-values) as regressors, and with *word type* as well as *preceding* and *following consonantal context* as random factors. Both regressors had a significant influence on d_{F2} , i.e. $\chi^2[3] = 25.3$, p < .001 (*time*) and $\chi^2[1] = 4.4$, p<.05 (*lexical frequency*), respectively. However, there was no interaction between the regressors ($\chi^2[3] = 0.9$).

A division of the data from age 42 to 95 years into frequent ($Zipf_{UK} > 4$) and infrequent ($Zipf_{UK} \le 4$) words suggests that the change may have proceeded more quickly in frequent words (see 6a). However, a mixed-effects model with the regressor *age* and the categorical factor *binary lexical frequency* (two levels: frequent, infrequent) and *word type*, as well as



BATH rel. to TRAP and START

Figure 6.6 Euclidean distance ratios as a function of age (*a*) and lexical frequency (panels b, c) with a further division of the latter into age groups in which BATH was stable (*b*) and unstable (*c*).

preceding and *following consonantal context* as random factors again failed to show an interaction between *age* and *binary lexical frequency*, whereas the significant effect of *binary lexical frequency* (χ^2 [1] = 5.1, p < .05) clearly suggests that more frequent words moved away from TRAP at least earlier than low-frequency words *during the period of change*, i.e. more frequent words were then closer to START.

During the period of change (between the ages of 66–68 years), d_{F2} was influenced by *lexical frequency* (now treated as a continuous regressor; see Figure 6.6c). This was confirmed ($\chi^2[1] = 6.1$, p < .05) by a mixed-effects model with *lexical frequency*—i.e. the Zipf_{UK}-values—as the independent variable and the same random factors as above. But there was no such influence during the years of phonetic stability (see Figure 6.6b), i.e. during

the periods between the ages of 42–51 years (with consistent / α / productions and $d_{F2} < 0$; *lexical frequency:* $\chi^2[1] = 0.1$, n.s.) and between 72–95 years (with consistent / α / productions and $d_{F2} > 0$; *lexical frequency:* $\chi^2[1] = 0.1$, n.s.).

4. General Discussion

The study has been concerned with biologically age-related and sociophonetic changes over the lifespan. We summarize the findings that relate to these two issues separately below.

4.1 Changes Related to Biological Age

The model of age-related changes to F1 in Reubold and Harrington (2015) predicts that F1 should track a physiologically induced change of f0 especially when f0 and F1 are close together in frequency. The reason why F1 should do so is derived from Traunmüller's (1981) perceptual model showing how the difference between F1 and f0 provides a cue for vowel height (see also Syrdal and Gopal 1986). Therefore, the biologically induced decline (and rise in older men) in f0 with increasing age should be matched by a corresponding change in F1, but only in phonetically high vowels in which f0 and F1 are close together and therefore likely to be perceptually integrated (Chistovich and Lublinskaya 1979). In low vowels, however, F1 is not expected to track f0 because, as a consequence of the high F1 in phonetically low vowels, f0 and F1 are too far apart in frequency for perceptual integration to occur. These predictions were substantiated by the data from Cooke and the Queen, for whom F1 tracked the declining (and in Cooke later rising) f0 with increasing age in high vowels, but not in low vowels. Moreover, there was a divergence for mid vowels between these speakers in a way that was consistent with the proximity between fo and F1. That is, given that the Queen's fundamental frequency was high and much closer to her F1 than in Cooke, then these differences for mid vowels between Cooke and the Queen in how F1 tracks f0 is exactly what we would predict from our model. This supports hypotheses I.a) and I.b) for the Queen data.

There was, however, no such relationship between f0 and F1 in Berghoff. f0 was roughly constant until the age of 50 years and decreased in later years. Although her f0 was closer to her average F1 than for Cooke, this seems not to have affected her F1. In Reubold et al. (2010), another professionally coached speaker, actress Margaret Lockwood, showed in contrast to all the other (non-voice-professional⁸) subjects of that study no F1 changes, even though her f0 had significantly lowered with age. There is some evidence from the vocal aging literature that speakers with trained voices cope differently with the age-related changes that apply to their voices than non-trained speakers (Linville 2001: 217–221). Actors are

trained in projecting their voices (e.g., on stage) and are reported to do so by producing a generally higher F1 than non-coached speakers (Master, Biase, Chiari and Laukkanen 2008), all other things being equal. Thus, we might speculate that voice-coached speakers are trained to maintain an auditorily constant vowel quality with increasing age to offset the age-dependent perturbation to formant frequencies induced by the declining f0. Moreover, Reubold (2012) had shown that not all of his (German) subjects' perceptual categorization of vowel height differences had been influenced by changes to the F1–f0 distance. Therefore, it is quite possible that not all listeners use this perceptual cue: they might therefore not perceive a perturbation to their own vowel height when f0 changes age-dependently.

Although no f0-related changes to F1 were predicted in low vowels (for the reasons stated earlier that they are far apart in frequency), we found for open vowels an F1-decrease for Cooke in very old age, and an F1-increase for Berghoff with increasing age. While the changes that apply to F1 in low vowels in 95-year-old Cooke can be explained by centralization (Rastatter and Jacques 1990), which could be due to age-related changes to the velocity of the movements of the muscles innervating the jaw (Linville 2001: 60–62), the further lowering of low vowels with increasing age in Berghoff is an unexpected finding (and, together with the non-significant changes to F1 in the Queen's low vowels, contra hypothesis I.c). On the other hand, Berghoff's F1 raising in later years could have come about not because of biological aging, but rather due to variation along the hypo- and hyperarticulation continuum and therefore the clarity of speech (Lindblom 1990). The higher F1 in Berghoff may come about because she simply had a less strict time limit in later recordings (given, e.g., Miller's 1981 findings showing how the vowel space is expanded in slow speech), especially in the rerecordings at age 70 (with virtually no time pressure at all). Hence, the higher F1 in low vowels may be a consequence of a wider mouth opening leading to a more expanded vowel space. A further indication that time pressure (and not biological age) was the driving force behind the changes to speech rate (and the inverse pattern of change to the vowel height dispersion measure) is that the changes to speech rate in Berghoff are non-linear, with an increase of speech rate in the first few years as a newsreader and with a later decrease.

4.2 Accent Change in Cooke

We had predicted (hypothesis IIa) that Cooke's BATH-words would be close to START in his mid-twenties (before he accommodated to American interlocutors), that BATH would shift toward TRAP in his middle years, but then back to START in later life. Our method of capturing the relative distance of BATH tokens between TRAP and START confirmed these predictions.

The only exception to this was 'Iraq', produced as [?irækh] at age 95, i.e. at a time of recording at which Cooke consistently—except for this

example-used a back vowel in BATH. 'Iraq' is one of those BATH words in which the second vowel may vary considerably, even within the same accent. Hall-Lew, Coppock and Starr (2010) have shown that the pronunciation of the second vowel in 'Iraq' may vary as a function of political identity (with US conservatives being more likely to be $/\alpha$ -users, and liberals being more likely to be /a/-users), even when controlling for regional accent.

Reubold and Harrington (2015) had only anecdotal evidence (see Clarke 2000: 17) that Cooke had changed his accent from Northern English to RP during his time at school. The additional data from 25-year-old Cooke showed that his accent has marked characteristics of RP including an unequivocally back / α / in the BATH lexical set. This variable changed to / α / sometime between the ages of 25 and 42. Cooke had become a permanent resident of the US at the age of 28 and claimed himself two years later to have changed his accent to one somewhere between typical 'American' and 'British' accents (see Clarke 2000: 148). His accent at that time retains characteristics of RP (e.g., non-rhoticity⁹) combined with marked standard American aspects, in particular the fronting of BATH toward $/\alpha$ typical of TRAP. We suggest that this blending of the varieties has come about for reasons of accommodation (Giles, Coupland, and Coupland 1991; Garrod and Pickering 2009).

Our proposal that Cooke accommodated to his American interlocutors does not necessarily mean that he did so because he wanted to sound more American. Imitation task experiments conducted in the laboratory (e.g., Babel 2010) have shown that speakers cannot avoid imitating their interlocutors, but also that the amount of convergence toward an interlocutor may be a function of social and cognitive (or attitudinal) factors. Upon emigrating, Cooke was strongly motivated to become a member of American society (he applied for US citizenship upon his arrival). He also spent a considerable amount of time travelling around the United States in these first years and came into contact with speakers of a diverse array of US English varieties: The outcome of this contact may have been a perceptual dialect leveling in favor of the American standard (see Clopper 2014) to which he then converged, but only to a certain degree. He retained this blending of RP and the American standard until the mid-1970s, when some vowels shifted back toward values more typical of RP.

There are studies showing second language (L2) attrition and first language (L1) reversion in senior bilingual subjects; these findings can be attributed to a reduction of contact with speakers of L2 and increased contact with the subjects' L1-speaking family and community after the subjects' retirement (De Bot and Clyne 1989; Clyne 2011; see also Blondeau, this volume). The analogy of these findings to those that we present here is that Cooke also reverted to an earlier acquired variety, and that he did so at a similar stage in life, i.e. during his late sixties. However, in contrast to the situation of the retired seniors in the aforementioned studies, a dramatic change in Cooke's social networks is unlikely, because, first of all, he did

not retire. Besides, all members of his family that surrounded him every day were Americans by birth, including his spouse.

According to his biographer (Clarke 2000: 500), Cooke felt more and more detached from American society in later years, beginning with the 1970s, and this brought 'gradual disenchantment.' Moreover, for most of the American public, he seemed to have remained the 'archetypal Englishman' (Clarke 2000: 1). This may have caused—as reviewers of an earlier version of this chapter pointed out—a shift in style to a more formal, more conservative, and therefore more RP-like, register, given the high prestige of RP in the US.

However, this view is challenged by the evidence of Cooke's gradual and not abrupt change from $/\alpha$ / to $/\alpha$ / in BATH between May 1975 and July 1977. During that period, his BATH vowels were phonetically intermediate between $/\alpha$ / to $/\alpha$ / whereas they were close to $/\alpha$ / between the ages 42–61 and close to $/\alpha$ / between 72–95 years of age. Moreover (and as predicted by hypothesis II.b), BATH vowels moved closer to $/\alpha$ / between May 1975 and July 1977 *incrementally* even within the same words (e.g. 'after').

Several earlier (e.g., Bybee 2002) and more recent (Hay and Foulkes 2016; Lin et al. 2014) studies have suggested that—contra the Neogrammarian hypothesis but consistently with usage-based models of speech—sound change may take place initially in words of high frequency. There is some limited evidence for this in our data: during Cooke's stable periods, in which BATH words were consistently produced with either $/\alpha/$ (in his earlier years) or /a/ (in his later years), there was no effect of lexical frequency: but there was (consistently with hypothesis II.c) a significant effect of lexical frequency during the few years in the 1970s in which Cooke switched from $/\alpha/$ to /a/ in BATH words such that words of high frequency changed earlier.

Most prior studies have demonstrated an interaction between lexical frequency and reductive sound changes such as lenition (e.g. Bybee 2002; Hay and Foulkes 2016; Hay et al. 2015; Lin et al. 2014). However, we are dealing with a non-reductive change in vowel quality, which others (e.g., Labov 2010) have found to be unaffected by lexical frequency. Changes to vowel quality during *second dialect acquisition* have been shown to be dependent on lexical frequency, with frequent words leading the change (Nycz 2013). This is in accordance with usage-based models, given that there are more updates to frequent words in the representations in memory by perceiving interlocutors speaking the new dialect.

So, how would it be possible that this new dialect wanes earlier in more frequent words, as it obviously does in Cooke, especially when he presumably still received input mostly from this second dialect, and not from the original one to which he reverted? A possible usage-based solution to this puzzle is that more frequent word tokens may lead to a deeper 'entrenchment,' i.e. a stronger impact on the representations in the speaker's memory than low-frequency words (Bybee 2006). We would further suggest that the distant memory representations in Cooke for BATH with /a/ prior to

emigrating were stronger for frequent than less-frequent words and that accents formed early in life¹⁰ may be more stable than those acquired after the critical period. Such a model is consistent with findings that speakers having acquired a second accent are more vulnerable to perturbations than speakers who retained their original accent (Howell, Barry, and Vinson 2006); in the latter group, early acquired and lifelong constantly repeated neuromotor patterns may simply be more 'entrenched.' The model may also be part of an answer to the question why speakers may increasingly use more conservative, obsolescent variants in older life (MacKenzie forthcoming) and why "speech about older events elicits older variants" (Hay and Foulkes 2016: 299).

In usage-based models, imitation is a by-product of the way in which exemplars that are absorbed into memory in conversational interaction can incrementally shift phonetic and social categories—when a person interacts with another person with different phonetic and/or social variants. This incremental shift in production that is a consequence of interaction could explain some of the non-linear patterns of change over Cooke's lifespan and the dependency of these changes on lexical frequency. The change, according to this model, is brought about by imitating and accommodating to interlocutors in dialogue (Bloomfield 1933; see also Trudgill 2008). This would also be an example of internal change 'from below' taking place within the individual (see Labov 1972: 178-180; Sankoff 2006). It is possible that Cooke's non-linear changes are 'from above' and due to style shifting during the period in which he changed his attitude toward American society: Under this interpretation, when he wanted to become a member of it, he converged toward his American interlocutors; when he later on felt increasingly detached from the American way of living, he diverged again from his American interlocutors by falling back to the accent established in early life. Nevertheless, our data showing incremental changes to vowel quality are not consistent with this view of change from above.

5. Conclusions

This chapter has presented evidence for both biologically age-related and sociophonetic changes during an adult's lifespan and also that these effects can to a certain extent be separated acoustically. The age-related changes for two of the three speakers in this study were a declining first formant frequency with increasing age that comes about for vowels in which F1 is in close proximity to the (declining) fundamental frequency. However, one speaker did not show this pattern, even though her f0 decreased in later years, just as it did for the other two speakers. We tentatively interpret these differences as being due to professional voice coaching, which may provide a way to maintain F1 despite the declining f0. Alternatively, it could be that speakers show different degrees of sensitivity toward the degree to which f0 and F1 are perceptually integrated.

The sociophonetic changes were a reversion from an acquired accent to one that had been produced prior to emigration. This was shown to occur incrementally and not abruptly involving a gradual change to vowel quality even within the same words over a two-year period. This change was led by lexically frequent words. However, we have demonstrated this so far in only one speaker. We therefore encourage further research from many more adults over the lifespan in future panel studies.

The general conclusion is that adults are affected over the lifespan by both age-related and sociophonetic changes that depend on linguistic and extra-linguistic experience, and that may also vary depending on a range of factors, such as listener-specific perception differences. Our interpretation of the sociophonetic data presented in this chapter is in terms of a usagebased model, in which adult speakers accommodate to interlocutors and in which speakers in old age may revert to earlier acquired, more entrenched and, therefore, more stable accents.

Notes

- 1 This research was supported by European Research Council grant number 295573 'Sound change and the acquisition of speech' (2012–17) to Jonathan Harrington. We thank Daniel Ezra Johnson and Benina Knothe for providing us with additional data; we also thank Carolin Sabath and Rebecca Stegmaier for segmentation and formant correction. We would also like to express our gratitude to the editors and two anonymous reviewers for their helpful comments.
- 2 For changes to children's vocal tracts and formants, see Kohn and Farrington (this volume).
- 3 The broadcasts were recorded in 1947, 1951, 1953, 1960, 1962, 1965, 1970-71, 1973-74, 1980-85, 1990-94, 1996-99 and 2000-04.
- 4 The messages were recorded in 1952, 1954–61, 1963–68, 1970–72, 1983, 1985, 1988 and 1995–2002.
- 5 PALM words are generally very rare; however, START is non-rhotic in Cooke and could be used as a replacement for PALM.
- 6 We use d_i as a shorthand notation to refer to log. Euclidean distance ratios on parameter *i* across all broadcasts.
- 7 We intended originally to compare frequency effects taken from SUBTLEX-UK with those taken from SUBTLEX-US (subtitles of US American films and television series: Brysbaert and New 2009). However, most of the BATH words uttered by Cooke in the 1975–77 databases were nearly equally frequent in both databases, with very few exceptions like e.g. 'ranching' ($\text{Zipf}_{UK} = 1.97, \text{Zipf}_{US} = 2.41$) or 'vast' ($\text{Zipf}_{UK} = 4.53, \text{Zipf}_{US} = 3.79$); therefore, the difference between Zipf_{UK} and Zipf_{US} was too small to draw any sensible conclusions about differences in U.S. or British usage of these words. We therefore opted instead for analyzing lexical frequency based only on SUBTLEX-UK.
- 8 Cooke, one of those subjects, had been a member of a student drama group and later attended Yale drama school (subject: stage direction); this does, however, not necessarily mean that he had received professional voice coaching, whereas Berghoff and Lockwood had attended actors' studios in drama schools, in which voice coaching is usually obligatory.
- 9 This may be surprising, given not only Cooke's accommodation to an American standard—and therefore usually rhotic—variety, but also that Cooke's supposed

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first (Northern English) accent, acquired in Lancashire, probably was characterized by some amount of rhoticity during his boyhood, as one reviewer pointed out.

10 The reader should be reminded that Cooke is likely to have acquired RP at the end of the critical period, i.e. at age 12 or 13, replacing his former 'Blackpool twang' (Clarke 2000: 17).

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