Disassociating the effects of age from phonetic change

A longitudinal study of formant frequencies*

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Our study aimed at disassociating age-related from phonetic changes in broadcasts by British-American radio commentator Alistair Cooke, spanning 60 years. Both the first formant (F1) and fundamental frequency (f0) in non-low vowels showed a falling-rising pattern with increasing age. We argue that this covariation may have a perceptual origin because the distance between F1 and f0 is a perceptual cue to vowel height. A covariation of F1 and F2 in low back vowels is also consistent with a perceptual explanation. By contrast, F1 changes in low vowels may be associated with physiological changes to the jaw-opening mechanisms. Finally, we discuss phonetic changes, showing accent reversion from General American towards Cooke's former Received Pronunciation over a thirty-year period.

1. Introduction

Many studies have made advances in quantifying sound changes in progress using the so-called apparent-time methodology (Bailey et al. 1991; Weinreich, Labov & Herzog 1968) by which phonetic change is inferred from comparisons between younger and older members of the same speaking community, based on the assumption that pronunciation has stabilized after a certain critical age. In vowel-based studies of sound change, the preferred parameters are often

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the first two formant frequencies (e.g. Labov 1994), since these index phonetic backness and height from which sound change in different varieties can be inferred empirically. However, these parameters are known to be influenced by speaker-specific attributes including both social and physiological factors such as age and gender (Peterson & Barney 1952). Age in particular can be confounded acoustically with phonetic changes. For example, there are many sound changes involving phonetic lowering or raising which have their greatest influence on the first formant frequency (F1). But as recent longitudinal (Harrington 2006; Harrington, Palethorpe & Watson 2007; Reubold, Harrington & Kleber 2010) and apparent-time (Linville & Fisher 1985; Scukanec, Petrosino & Squibb 1991; Xue et al. 1999; Xue & Hao 2003) studies have shown, F1 also decreases with increasing biological age. Consequently, F1 raising or lowering in younger compared with older speakers may not necessarily be due to a sound change in progress, but could instead arise as a result of the aging voice's influence on the acoustic signal.

The present study is an extension of an analysis in Reubold, Harrington & Kleber (2010) which was concerned with changes to fundamental frequency and formant frequencies in over 10 hours of British-American radio commentator Alistair Cooke's *Letter from America* broadcasts recorded between 1947 and 2004 (in which he was between 38 and 95 years of age). In the following we will discuss changes which have previously been associated by Reubold, Harrington & Kleber (2010) with age-related physiological changes.

Reubold, Harrington & Kleber's (2010) motivation for choosing this speaker was partly because the authors had access to over half a century of broadcast material delivered almost weekly in a comparable speaking style and under a similar communicative setting. Yet Alistair Cooke is also special due to biographical circumstances that included in particular a long-term relocation from England to New York, which in turn might have led to phonetic changes in adulthood. Below, we discuss in detail a subsequent, rather informal analysis which indeed reveals such phonetic changes. Therefore, Cooke's data is a valuable test case for the disassociation of age-related and phonetic influences to vowel formants.

The phonetic changes presented below suggest that, rather than Cooke's accent becoming increasingly 'American' with the passage of time (which is to be expected, given that he lived in the United States from the age of 29 years), there is instead some evidence that his accent reverts in older life towards Standard Southern British English/Received Pronunciation (RP), the variety that he is likely to have spoken before he emigrated to America. To our knowledge, we present here the first phonetic study of such a case of accent reversion.

2. Data

2.1 Speaker

Our three analyses in this paper and previous analyses in Harrington, Palethorpe & Watson (2007) and Reubold, Harrington & Kleber (2010) are based on archival recordings of Alistair Cooke, a British-American radio commentator, who is said to have made the world's longest running speech radio broadcast (*Letter from America*). We provide here a brief biography, based on Cooke (2007) and on Cooke's biography in Clarke (2000).

Alistair Cooke was born on November 20th 1908 in Salford, Lancashire (in North West England, nowadays Greater Manchester) to a metal smith and to a mother of Irish origin. After his education at the Blackpool Grammar School, he studied at Jesus College, University of Cambridge, England. He went to America for the first time in 1932 under a Harkness Fellowship. He married an American and moved back to England in 1934 when he became a correspondent for the American National Broadcasting Company (NBC). With his program *London Letter*, Cooke began a type of broadcast which he continued – with some interruptions due to the Second World War – until the end of his life, namely a weekly 15 minute report on cultural, social, and political themes from one continent to the other. After moving permanently to America in 1937, he continued this type of broadcast for the British Broadcasting Corporation (BBC), reporting about America to British listeners with *Mainly about Manhattan* (1938–1939), which was the short-lived predecessor of *American Letter* (starting in 1946), a BBC radio broadcast that was renamed in 1950 into *Letter from America*. This (almost) weekly broadcast was continued until 20 February 2004, only a month before Cooke's death (30 March 2004) at the age of 95. This series was broadcast for 58 years without interruption.

2.2 Materials

Reubold, Harrington & Kleber (2010) analyzed 10.5 hours of speech, i.e. 47 broadcasts of *Letter from America* recorded between 1947 and 2004, more precisely in the 1940s and 1950s (1947, 1951, 1953), the 1960s (1960, 1962, 1965), the 1970s (1970–1971, 1973–1974), the 1980s (1980–1985), the 1990s (1990–1994, 1996–1999), and the 2000s (2000–2004), in order to cover the biological age from 38 to 95. The mean duration of these recordings was 13.5 minutes.

At the time of the study in Reubold, Harrington & Kleber (2010), no transcriptions of Cooke's speeches were available, but in the meantime the BBC have published transcripts of most of Cooke's broadcasts. These were used to automatically segment and label a subset of the data (see General Method section for details). A subsequent correction of these segments and labels by an L1-English phonetician which included an association of each vowel token to the corresponding Lexical Set[1] allowed for an informal descriptive analysis of phonetic changes which revealed an accent change to be described below.

3. General method

Since no segmentations of Cooke's speech were available to Reubold, Harrington & Kleber (2010), they instead calculated f0 and formant frequency averages (per year of recording) in all voiced frames of the broadcasts to track general trends of change for these parameters (as far as formants are concerned, this method is comparable to Linville & Rens' (2001) measurements of the first three spectral peaks of Long-Term Average Spectra, LTAS). Fundamental frequency and the synchronized first four formant frequencies were calculated with a frame shift of 5 ms and a window length of 20 ms. Linear regression techniques were applied to the data in order to test for differences in the rate of change of f0 and of the first three formant frequencies as a function of age. Some of these data from voiced frames were re-used in the present study.

For the follow-up study in the current paper, the aforementioned transcripts of the *Letter from America* broadcasts were used to automatically segment and label the audio data by means of a combination of automatic grapheme-phoneme conversion and a forced-alignment algorithm using the Munich Automatic Segmentation system (MAuS; Schiel, Draxler & Harrington 2011). To reduce prosodically induced variation of the measured acoustic parameters, we decided to analyze only those monophthongal vowels which were the nuclei of primary-stressed syllables in nuclear-accented words. For those vowels only, the automatically derived segments and their labels were manually corrected, if necessary, by an L1-English phonetician. Because such corrections are very time-consuming, only a subset of the database was selected in order to include one broadcast per decade (with the exception of the 1940s). For the analysis, broadcasts from each of 1951, 1960, 1970, 1981, 1993, 2004 were chosen (i.e. with Cooke aged 42, 51,

1. A Lexical Set is a group of words in which particular vowels are pronounced in the same way, and the term "Standard Lexical Set" refers to the two Standard pronunciation norms that Wells (1982) used, the *Standard Southern British English/Received Pronunciation* (RP), and *General American* (GenAm). These Lexical Sets are represented by keywords. One example is the keyword for Standard Lexical Set 7: BATH, which stands for words that are pronounced with the same vowel as in the word *bath* (RP: [bɑːθ], GenAm: [bæθ]), e.g. *staff, class, ask, fasten*.

61, 72, 84, and 95 years of age, respectively). The mean duration of these recordings was 13 minutes and 18 seconds, with durations varying between 12 minutes, 42 seconds, in 2004, and 14 minutes, 2 seconds, in 1960 (standard deviation = 27.6 seconds). The total duration of the materials analyzed in the current study was 1 hour, 47 minutes and 26 seconds.

The L1-English phonetician also recorded clear cases of divergences from the vowel labels proposed by the MAuS system which converts orthographic strings to RP-like phonemic strings, i.e. she recorded divergences from RP-like monophthongs. The vowel tokens were additionally labeled with one of the Standard Lexical Set keywords (Wells 1982); Lexical Sets with too few tokens in the current database had to be omitted (e.g. FOOT, i.e. words produced with an [ʊ]-nucleus of the stressed syllable both in Received Pronunciation and General American). The distribution per year of the remaining 13 Lexical Sets is shown in Table 1.

Table 1. The 2229 monophthongal vowels analyzed in this study, represented by Standard Lexical Set keywords, and the number of tokens per year of recording*

LexicalSet keyword/year	1951 (42)	1960 (51)	1970 (61)	1981 (72)	1993 (84)	2004 (95)	RP	GenAm
BATH	7	6	8	7	3	6	ɑː	æ
DRESS	86	81	68	92	60	99	e	ɛ
FLEECE	27	54	23	30	26	31	iː	i
FORCE	4	10	11	2	4	6	ɔː	or
GOOSE	20	13	17	9	17	13	uː	u
KIT	68	53	40	38	50	58	ɪ	ɪ
LOT	51	37	36	41	30	15	ɒ	ɑ
NORTH	19	19	13	9	11	13	ɔː	ɔr
NURSE	19	14	21	11	30	17	ɜː	ɜr
START	9	11	9	14	9	8	ɑː	ɑr
STRUT	67	41	35	39	33	32	ʌ	ʌ
THOUGHT	16	19	18	13	14	20	ɔː	ɔ
TRAP	54	53	47	44	39	32	æ	æ

*Cooke's ages are given in brackets. The last two columns give phonetic labels (IPA) for the most common pronunciations of these Lexical Set vowels in the standard accents that Wells' 1982: 123 used, Standard Southern British English/Received Pronunciation (RP) and General American (GenAm)

The first three formant frequencies (F1, F2, F3) in these 2229 vowels were checked and corrected by a trained phonetician. All analyses reported below in Experiments 1–3 were based on f0 and formants measured at the vowels' temporal midpoints.

Due to our findings of an accent change in Cooke's broadcasts, which we will describe in the following section, we decided to quantify age-related changes by analyzing formants of vowels from only those nine Lexical Sets that did not change phonetic vowel quality with the passage of time, and to quantify subsequently phonetic changes in BATH, LOT, THOUGHT, and DRESS vowels (i.e. the vowels in which a phonetic quality change was perceptible). The series of experiments was necessary in order to be able to quantify phonetic changes by normalizing for the age-related, non-phonetic effects that affect formant frequencies.

4. Previous results and conclusions

Before we describe the details of the present study, we review the main findings and interpretation of both our previous research (Reubold, Harrington & Kleber 2010) and of the subsequent, rather informal descriptive analysis of phonetic changes to be found in Cooke's broadcasts described in this study.

4.1 Results of Reubold, Harrington & Kleber (2010)

The analysis of f0 and F1–3 in voiced frames of the 10.5 h dataset of Reubold, Harrington & Kleber (2010) revealed no significant changes to F2 or F3, but, as can be seen in Figure 1, a decreasing, then increasing pattern of both of parameters F1 and f0.

A break-point analysis (Baayen 2009) showed that the datasets of the two age-dependent parameters, f0 and F1, could both be modeled by two linear regression analyses with similar break points (at the age of 87–88 years of age). This result suggested that f0 and F1 followed a similar and possibly related trend which emerged most clearly when both parameters were represented on a logarithmic rather than linear Hertz scale. The results of this analysis showed that F1 and f0 were found to follow a similar falling-rising trend with increasing age: comparisons of the rates of change showed only a slightly steeper decline in F1 than in f0, and a non-significant difference in the rates of change in the rising trends at the more advanced age.

4.2 Conclusions from Reubold, Harrington & Kleber (2010)

After discussing and more or less rejecting several possible reasons for the f0-F1 covariation, Reubold, Harrington & Kleber (2010) proposed a model for age-related changes in which physiologically-induced age-related changes to f0 (that come about because of changes to the morphology of the vocal folds) were being tracked by F1. More specifically, the authors reasoned that, since the perceptual

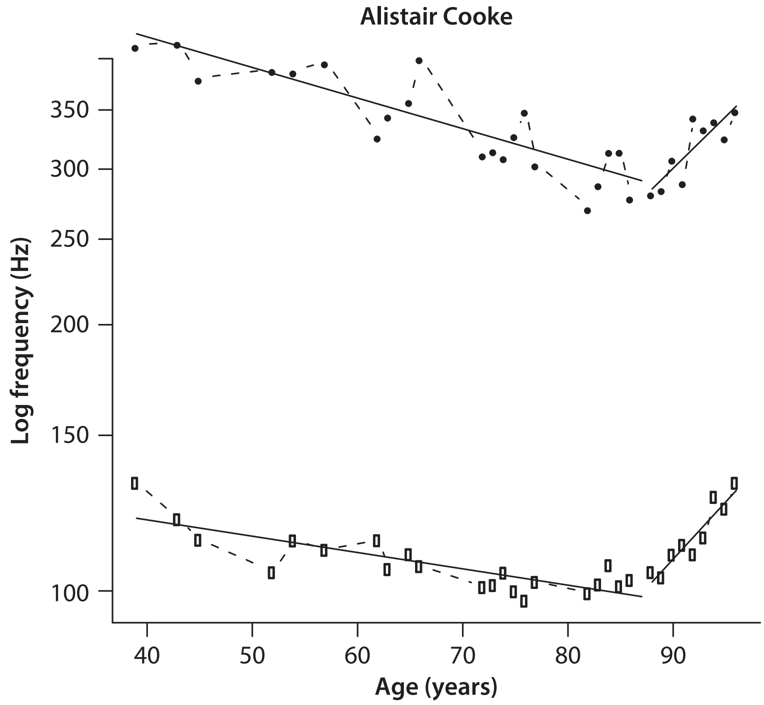

Figure 1. Right panel of Figure 3 of Reubold et al. (2010: 642), showing log. f0 (unfilled circles) and log. F1 (filled circles), averaged per year, as a function of chronological age with superimposed regression lines through the scatter

difference between the first formant and fundamental frequency may be an important perceptual cue to phonetic height (Traunmüller 1981), such F1 changes may be associated with the need for the speaker to recalibrate the F1-f0 difference as the fundamental frequency changes with increasing age which might cause some kind of perturbation of the vowel height percept.

4.3 Informal descriptive analysis of phonetic changes

To our great surprise, our descriptive analysis showed that Cooke's pronunciation, especially of monophthongal vowels, had clear characteristics of an accent close to *General American* (GenAm) in earlier years, and characteristics resembling an accent close to *Standard Southern British English/Received Pronunciation* (RP) in later years. In the continuum between GenAm and RP, Cooke never seems to reach its endpoints, i.e. he has never totally adapted to GenAm nor reverted his accent completely to RP. For example, Cooke never uses rhoticity in vowels of the Lexical Sets NURSE, START, or NORTH, whereas GenAm is a rhotic accent, i.e. one of its features is the r-coloring in these vowels. Yet Cooke's speech can be said to be certainly much nearer to GenAm in the recordings from the 1950s–1970s and much nearer to RP in the 1980s–2000s.

Four of 13 Lexical Sets analyzed were judged to be affected by these phonetic changes, i.e. BATH, LOT, THOUGHT, and DRESS varied from more GenAm-like to more RP-like realizations, while the remaining nine Lexical Sets (FLEECE, KIT, GOOSE, FORCE, NURSE, NORTH, TRAP, START, and STRUT) did not change in phonetic quality.

The proposed phonetic changes are as follows:

a. We perceived a very clear change in words like *after*, *half*, *last* in the BATH Lexical Set from a front [æ] typical of GenAm in the 1970s to the 1980s towards a more retracted [ɑː] more characteristic of RP from the 1980s onwards.
b. In the 1950s, Cooke produced many vowels from the Lexical Set LOT such as *doctor, shop, not* with a quality characteristic of the GenAm [ɑ], whereas from the 1980s this set is pronounced with RP-like [ɒ]. Such differences correspond to the differences observed by Wells (1982) between GenAm and RP LOT.
c. In the 1950s, Cooke produced the vowels in words like *all*, *also*, *autumn, talk*, i.e. ones from the Lexical Set THOUGHT with a more open, less rounded quality than in later years. This also seems to parallel a shift between the two varieties: more specifically, Wells (1982: 145) notes that GenAm THOUGHT is more open and has less rounding than its RP counterpart.
d. There is some evidence auditorily that Cooke's vowels in words like *any, friend, end* from the DRESS Lexical Set shifted towards a slightly more raised quality between the 1950s and 1980s. This too could correspond to the subtle difference between the varieties: here Wells (1982: 128) notes that DRESS is phonetically slightly raised in RP compared with its GenAm counterpart.

5. Aims of the current study

5.1 Age-related changes

Reubold, Harrington & Kleber (2010) had proposed that there is an age-related covariation of F1 and the fundamental frequency, because the distance between these parameters has been shown to be relevant for vowel height percepts and a physiologically-driven change in one parameter might cause speakers to maintain the F1-f0 distance by adjusting the other parameter. Yet the F1-f0 difference has been shown to be a less invariant acoustic feature of (perceived) vowel height than originally expected, and its advantage over F1 as a measure of vowel height may be restricted to certain areas in the vowel space (Traunmüller 1981, 1991; Di Benedetto 1987, 1994, 2003; Hoemeke & Diehl 1994; Fahey, Diehl & Traunmüller 1996). Traunmüller (1981) found that the effectiveness of the F1-f0 distance as a cue to vowel height is dependent on the distance between F1 and f0, i.e. the nearer F1 and the fundamental frequency are to each other, the more likely it is that this distance is used as a perceptual cue to vowel height (therefore, F1-f0 should be an especially salient cue to height in phonetically high vowels for which F1 and f0 are closest together in frequency).

Reubold, Harrington & Kleber (2010) analyzed very global measures, i.e. F1 and f0 derived from all voiced frames (including phonetically changing vowels, as our subsequent informal descriptive analysis has shown), and reasoned that the covariation of f0 and F1 might be the result of the perceptual relevance of the F1-f0 difference. What is not known, however, is whether such an association between f0 and F1 is vowel-dependent. On the one hand, high vowels may show the greatest degree of age change because of the relatively close proximity of their (low) F1 to the intrinsically high fundamental frequency of phonetically high vowels. On the other hand, age change may have a marginal influence on high vowels because the already low F1 places constraints on the further degree to which F1 can fall. Exploring vowel-specific age-dependent interactions between f0 and F1 is one of the main aims of this paper.

A second aim is to determine whether there are any age-related influences on F2. So far, there has been only inconclusive evidence about whether F2 is affected by physiologically based age changes (e.g. Linville & Rens 2001, who also show gender differences in the age-related F2 changes). Reubold, Harrington & Kleber's (2010) conclusion that F2 does not (consistently) change with age is based on longitudinal analyses of schwa and of voiced frames. In the present study we will investigate whether F2 is equally unaffected by age across different vowel types.

5.2 Phonetic changes

Finally, a third aim is to establish quantitative evidence for phonetic changes in adulthood from longitudinal data. This part of the investigation builds upon some studies in longitudinal design in which speakers have been shown to participate in community changes after the critical age (Cedergren 1987; Trudgill 1992; Harrington, Palethorpe & Watson 2000a, 2000b, 2005; Harrington 2006, 2007; Sankoff 2004; Sankoff & Blondeau 2007). A related aim is to explore the extent to which any such phonetic changes can be separated acoustically from changes due to biological age.

6. Experiment I

The purpose of this experiment was to extend the analyses in Reubold, Harrington & Kleber (2010) in order to test whether their result of an association between f0 and F1 can be found in vowels of different quality. To do so, we excluded vowels descriptively being judged as changing phonetically (i.e. vowels of the Lexical Sets BATH, LOT, THOUGHT, and DRESS). One of the main aims was to test the hypothesis that the falling-rising pattern in F1 and f0 with increasing age should be manifested primarily in phonetically high, but not low, vowels.

6.1 Method

For the analysis we chose vowels from nine Lexical Sets which we judged to change phonetically minimally over the years; these vowels were separated into phonetically high (FLEECE, KIT, and GOOSE), mid (NURSE, FORCE, and NORTH), and low (TRAP, START, and STRUT) vowels, respectively. We averaged F1 measured at the vowels' temporal midpoints per year of recording and per vowel group (high, mid, and low) and fitted polynomials to the resulting data (with the logarithm of F1 as the dependent variable and age as the regressor). As a control, the same polynomial regression fitting was applied to F1 aggregated by year across all of the utterances' voiced frames following the methodology in Reubold, Harrington & Kleber (2010).

Additionally, to test the correlation of F1 and f0 within the nine Lexical Sets, we applied a Generalized Linear Mixed Model (GLMM) to the raw data (i.e. one pair of an f0 and F1 value for each vowel token) with log. F1 as the dependent variable, log. f0 as the regressor (i.e. as first, numerical independent variable), VOWEL GROUP (3 levels: *low* vs. *mid* vs. *high* vowels) as the second, factorial independent variable, and LEXICAL SET (the nine levels: *TRAP*, *STRUT*, *START*, *NURSE*, *NORTH*, *FORCE*, *KIT*, *GOOSE*, and *FLEECE*) as a random factor. For the post-hoc tests, we conducted the same analyses with the regressor f0, but without VOWEL GROUP, and instead separately for the low, mid, and high vowels. Another test was run on the data of each of the 9 Lexical Sets in which the correlation between log. f0 and log. F1 was quantified by linear regression.

6.2 Results

The results in Figure 2 show a pattern of F1 change as a function of age that is similar for phonetically high vowels and voiced frames: in both cases, there is clear evidence of a U-shaped pattern. There is also some decrease and later increase of F1 to be found in mid vowels. The pattern for low vowels is by contrast very different and in the shape of an inverted parabola (∩-shaped).

Three datasets (voiced frames, high, and low vowels) were found to be significantly dependent on age (third order polynomial regressions for voiced frames (Adjusted $R^2 = 0.97$; $F[2,3] = 63.9$, $p < 0.05$) and low vowels (Adjusted $R^2 = 0.94$; $F[2,3] = 26.5$, $p < 0.05$); second order polynomial regression for high vowels: $R^2 = 0.90$; $F[2,3] = 23.5$, $p < 0.05$). The data for mid vowels were not statistically significant depending on age.

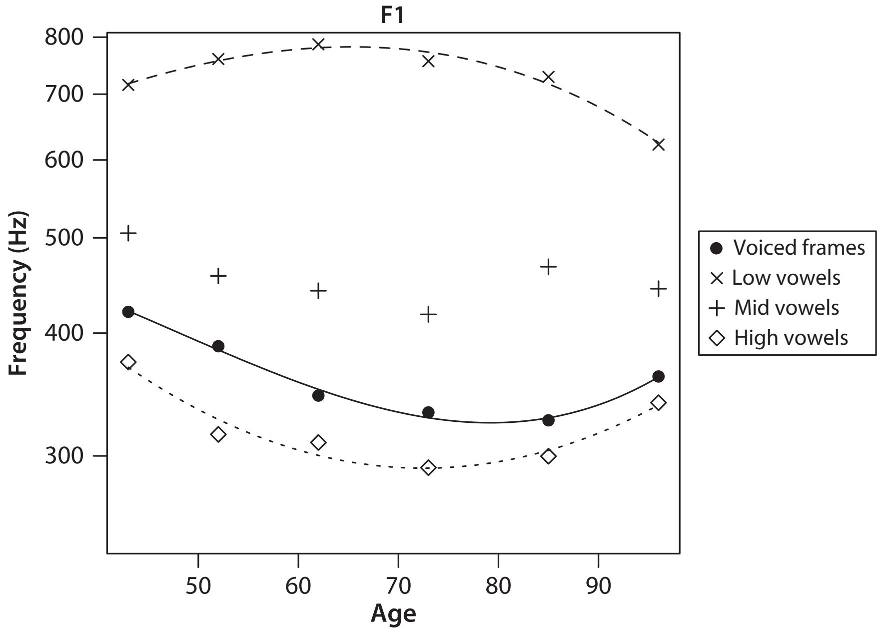

Figure 2. First formant frequency measured in voiced frames and at the midpoints of low (START, STRUT, and TRAP), mid (FORCE, NORTH, and NURSE), and high (FLEECE, GOOSE, and KIT) vowels, in each case averaged by age of the speaker

Concerning the correlation of F1 and f0, the GLMM with the regressor f0 and the additional factor VOWEL GROUP (low vs. mid vs. high) showed two main effects: the effect of VOWEL GROUP ($\chi^2[2,6] = 30.5$, $p < 0.001$) simply shows that low, mid, and high vowels differ in their F1 values; the effect of f0 ($\chi^2[1,4] = 13.4$, $p < 0.001$) shows that log. f0 and log. F1 are correlated. The significant interaction between log. f0 and VOWEL GROUP ($\chi^2[2,8] = 9.0$, $p < 0.05$) shows a different pattern of correlation between F1 and f0 across the three different vowel groups: while there is no effect of f0 on the first formant frequency in low vowels ($\chi^2[1,4] = 0.1$, n.s.), its effect is rather strong in high vowels ($\chi^2[1,4] = 15.8$, $p < 0.001$), and less strong, but still statistically significant, in mid vowels ($\chi^2[1,4] = 3.9$, $p < 0.05$).

Figure 3 shows that there are obvious differences in the correlation between F1 and f0 even within the high and mid vowel groups (first two rows). Statistically significant (positive) correlations could be found only for FLEECE ($F[1,105] = 22.3$, $p < 0.001$), GOOSE ($F[1,53] = 6.3$, $p < 0.05$), and FORCE ($F[1,15] = 7.2$, $p < 0.05$). The association between F1 and f0 did not quite reach significance in KIT ($F[1,208] = 2.7$, $p < 0.1$).

6.3 Discussion

The results show a vowel-dependent relationship between F1 and increasing age: for high vowels, there was a U-shaped falling-rising pattern whereas for low vowels it was ∩-shaped, i.e. rising-falling.

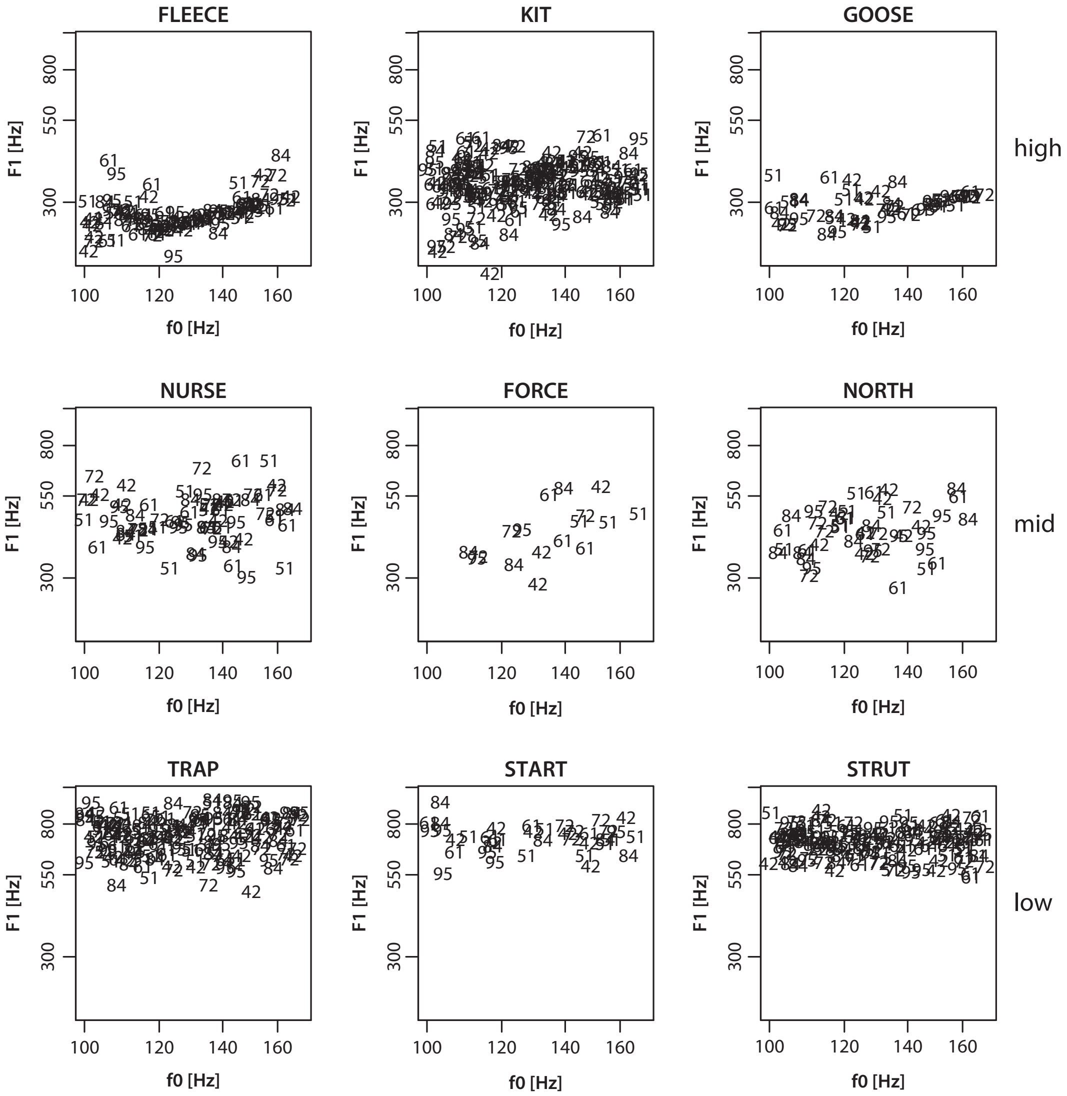

Figure 3. Distribution of F1 as a function of fundamental frequency. The data points are represented by the speaker's age values. The rows correspond to the levels of the independent factor in the statistical analysis (GLMM)

According to Reubold, Harrington & Kleber (2010), age-related changes to F1 might be directly dependent on equivalent age-related changes in fundamental frequency due to the need to maintain a constant perceptual distance between f0 and F1, which cues vowel height. This conclusion is supported in the present results mainly for high and partly also for mid vowels in which F1 and f0 are close together, but not for low vowels in which F1 and f0 are far apart, i.e. Figure 3 shows that the correlation between f0 and F1 increases with phonetic height which may be because f0 and F1 are progressively closer together for increasing phonetic vowel height. Yet even in those vowels showing the most obvious correlation, i.e. in the high tense vowels FLEECE and GOOSE, the association between F1 and f0 is weakened when f0 is in the region below approximately 120 Hz in which more outliers from the trend are to be found.

These observations are in accordance with Traunmüller's (1981) findings that (a) the relationship of vowel height percepts with covarying F1 and f0 weakened at very low fundamental frequencies irrespective of the F1-f0 distance, and that (b) this relationship was dependent on how close F1 and f0 were together, i.e. it was more robust in phonetically higher than in lower vowels (Hoemeke & Diehl 1994 also supported this finding). The latter finding led Traunmüller (1981: 1472) to the assumption that listeners relate the first formant frequency to the nearest spectral prominence in the signal when judging vowel quality. In most non-low vowels, f0 is the nearest spectral prominence to F1, whereas in low and/or back vowels, F2 may come closer to F1 than f0. Therefore, in some vowels, in which F1 is close to F2, a certain covariation of F1 and F2 is to be expected for perceptual reasons, i.e. to maintain perceived phonetic quality.

Thus the idea developed in Reubold, Harrington & Kleber (2010) that F1 tracks age-dependent changes in f0 for perceptual reasons seems to apply only to high (and partially for mid) vowels in which F1 and f0 are close together. The rising-falling pattern for F1 in phonetically low vowels must therefore have a very different origin. The initial rise between the ages of 42 (the first recording we analyzed) and 61 years could have come about for reasons to do with hyperarticulation and increasing the clarity of speech (Lindblom 1990) i.e. the F1 in low vowels may be a consequence of a wider mouth opening in low vowels (leading to a more expanded vowel space – Ferguson & Kewley-Port 2007). One possibility that may account for the final decrease of F1 in low vowels observed in Figure 2 is that with increasing age, speakers tend not to open their mouths as much because of slower movements of the muscles innervating the jaw (Linville & Rens 2001: 60–62; Monemi, Thornell & Eriksson 1999; Mioche et al. 2004). If so, then F1 would be progressively lowered in phonetically low vowels with increasing age: it is possible that this is the physiological basis of the overall compression of the acoustic vowel space that has been found in older adults (Rastatter & Jacques 1990).

7. Experiment II

In the second experiment, we tested the covariation between the first two formant frequencies and age. Following Traunmüller (1981), F1 and F2 are more likely to be perceptually integrated when the auditory distance between them is small. Taking into account Traunmüller's findings and those from Experiment I, the following predictions can be made.

H1: There should be no age-dependent covariation between F1 and F2 in high front vowels in which F1 and F2 are very far apart from each other (FLEECE, KIT).
H2: In high back vowels (GOOSE), in which F1 and F2 are much closer, F2 will covary with F1. Moreover, given the findings in Experiment I, f0, F1, and F2 should all show a similar parabolic U-shape.
H3: F1 and F2 can be expected to covary with increasing age in open back vowels like START and STRUT to the extent that the first two formant frequencies are close together. Following the results from Experiment I, F1 and F2 for these vowels should both follow the shape of an inverted parabola with increasing age. The same may also apply to TRAP, again depending on how close together the first two formant frequencies are for this speaker.

7.1 Method

Linear regression analysis was carried out with log. F2 as the dependent variable and log. F1 as the regressor. F1 and F2 were extracted at the vowel's temporal midpoint and averaged per vowel type and per year of recording.

7.2 Results

Figure 4 shows the distribution of the vowels in F1 × F2 planes. The data points are represented by the speaker's age values in a space whose dimensions are scaled logarithmically. No correlation between F1 and F2 could be found for FLEECE ($F[1,4] = 0.78$, n.s.) nor for KIT ($F[1,4] = 0.03$, n.s.). There was also no correlation between F1 and F2 for GOOSE ($F[1,4] = 0.04$, n.s.) nor for TRAP ($F[1,4] = 0.04$, n.s.). A positive correlation between F1 and F2 was found both for START ($R^2 = 0.67$, $F[1,4] = 11.2$, $p < 0.05$) and for STRUT ($R^2 = 0.78$, $F[1,4] = 18.5$, $p < 0.05$).

7.3 Discussion

Consistent with our first hypothesis, we found no evidence for an age-dependent covariation between F1 and F2 in the high front vowels in which F1 and F2 are far apart.

There was no evidence to support the second hypothesis in which f0, F1, and F2 were predicted to covary in high back vowels, to the extent that these are close together. However, Cooke's F1 and F2 in GOOSE were further than 5 Bark apart: we suggest therefore that F2 does not track F1 because their frequencies are too far apart for these formants to be perceptually integrated: that is, an integration applies only if two formants are closer together than a critical distance of 3–3.5 Bark (Chistovich & Lublinskaya's 1979 so-called 'center of gravity' effect). Such

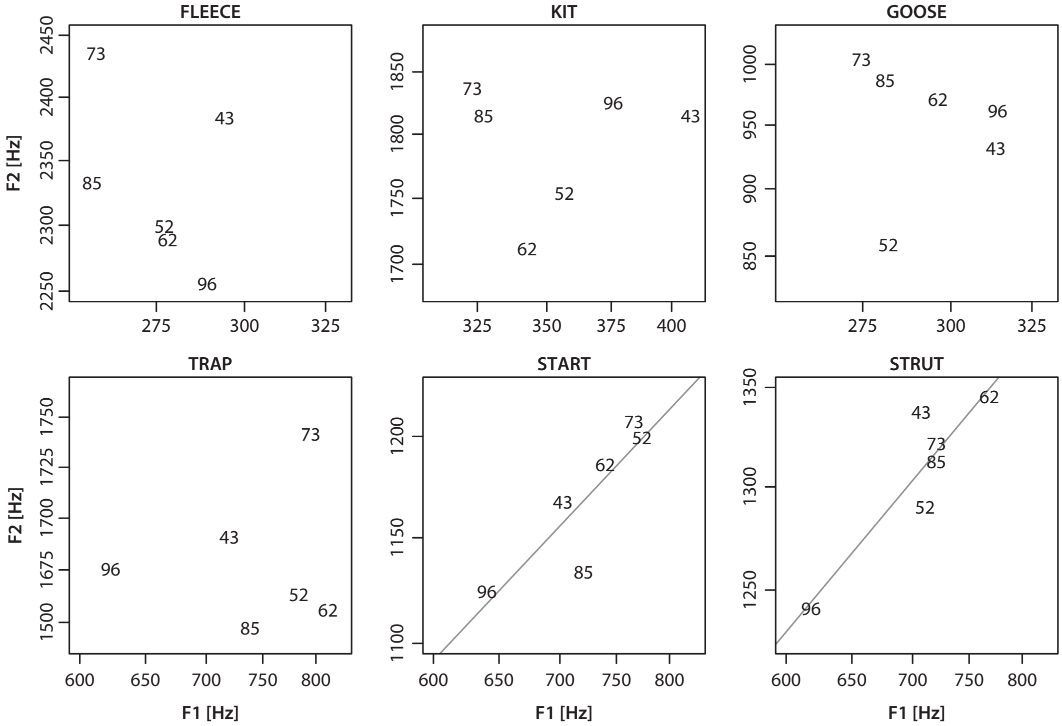

Figure 4. Covariation of F1 and F2: median values of F2 as a function of F1 in high (FLEECE, KIT, and GOOSE) and in low (TRAP, START, and STRUT) vowels. For covarying START and STRUT vowels, regression lines are superimposed

an integration has been reported to play a role in listeners' classification of vowels (3-Bark hypothesis, Syrdal & Gopal 1986).

Our results support the third hypothesis in which F1 and F2 were predicted to covary with increasing age in STRUT and START, i.e. in those vowels for which the separation between F1 and F2 was less than 3 Bark. F2 did not track F1 in TRAP. However, the F1 and F2 distance for Cooke's TRAP was greater than 3 Bark: thus, once again, there may be no need to adjust F2 in relation to an age-dependent changing F1 (given that F1 and F2 for TRAP exceed the critical distance of 3.5 Bark and are therefore less likely to be perceptually integrated).

So far, our results are compatible with the idea of age-dependent changes in formant frequencies that, for non-low vowels, are related to age-dependent changes in the fundamental frequency. In the next section, we consider the extent to which there is also evidence for phonetic change in the lifespan of the speaker.

8. Experiment III

In Section 4.3. above, we presented our impression that there are phonetic changes to some of Cooke's vowels with the passage of time. More specifically, our judgments were that (much to our great surprise), Cooke shifted his accent from GenAm back to RP over the period from around 1950 to 1980. The changes we observed seem to be restricted to four Lexical Sets: we perceive a retraction of BATH, more rounding in LOT, an opener, less rounded quality in THOUGHT, and a more raised quality in DRESS.

We sought to quantify these four impressionistic observations in Cooke's vowels as follows. The predictions relate to the changes we expect to see between the 1950s and 1980s in the broadcasts.

H1: We expected BATH to shift from the open front TRAP toward the open back START between the 1970s towards the 1980s (this is the period in which we observed these auditory changes).
H2: LOT is expected to shift from START towards NORTH corresponding to the shift from GenAm [ɑ] towards RP [ɒ].
H3: We also expect a similar shift in THOUGHT between START and NORTH based on our auditory impressions that this vowel has shifted from GenAm to a phonetically closer, more rounded RP variant.
H4: The perceived increase in phonetic height from Cooke's GenAm towards RP production of DRESS between the 1960s and the 1990s should be manifested as a shift away from TRAP towards KIT.

8.1 Method

We chose for each phonetically changing vowel a pair of phonetically stable anchor vowels which we denote by Anchor_1 and Anchor_2: for BATH vowels, the anchor pair was TRAP and START, for both LOT and THOUGHT, Anchor_1 was NORTH and Anchor_2 was START, and for DRESS the anchors were KIT and TRAP.

We measured the Euclidean distance (in Bark) of each token (see Table 1 for the number of tokens per year) of BATH, LOT, THOUGHT, and DRESS to the mean of each of the corresponding two anchor vowels (these means are denoted A_1 and A_2) in either the F1 or the F2 dimension. We thereby obtained for each token two distances, E_1 (the token's distance to A_1) and E_2 (its distance to A_2). We then calculated

$$d = \log(E_1/E_2)$$

which gives a relative measure of the vowel token's distance between the two anchors A_1 and A_2. More specifically, if d is 0, the vowel token is equidistant between the two anchors. If $d < 0$, the vowel is nearer to anchor A_1, if $d > 0$, it is nearer to A_2. We applied polynomial or linear regression fitting to test for changes over time, with the dependent variable being d, and age the regressor (see also Harrington, Kleber & Reubold 2008 for further details on this metric and its applicability to measuring vowel quality).

For comparison, we also applied polynomial or linear regression fitting to test for changes over time in the raw formant data (i.e. the dependent variable here was either F1 or F2 not calculated with respect to any anchors).

8.2 Results

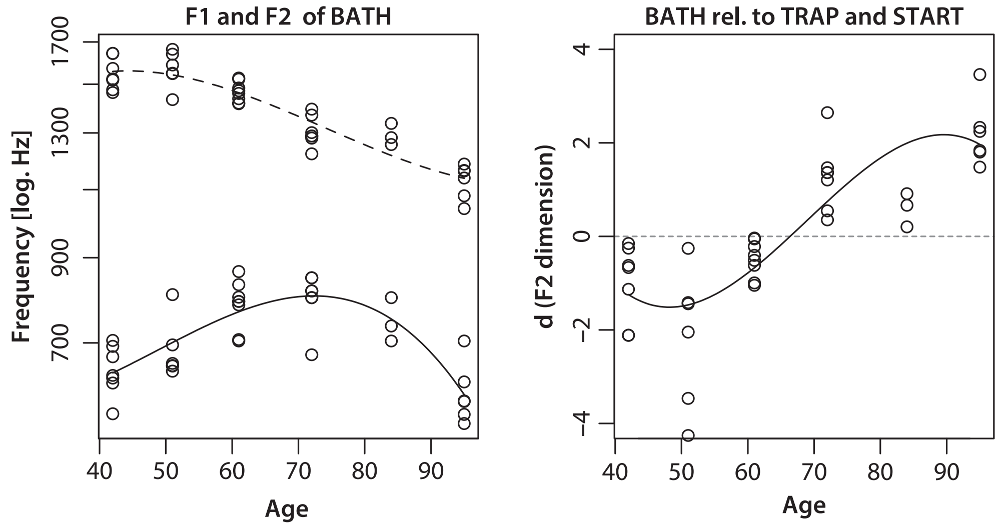

Figure 5. Left panel: F2 in BATH vowels as a function of age. Right panel: The log. Euclidean distance ratio in the F2 dimension for BATH related to the anchors TRAP and START as a function of age. Regression curves are superimposed

BATH Our prediction was that BATH should shift from TRAP towards START. The evidence for this is supported in two ways. Firstly (Figure 5 left panel), there is a significant trend for F2 to lower with increasing age ($R^2 = 0.84$, $F[3,33] = 67.1$, $p < 0.001$). Secondly, in Figure 5 (right panel), BATH is acoustically closer to START than to TRAP with increasing age and this trend is also significant ($R^2 = 0.637$, $F[3,33] = 22.1$, $p < 0.001$). This shift was very abrupt, as shown by the large separation between the non-overlapping distributions before and after the shift between 1970 and 1981.

LOT Our prediction was that LOT would shift roughly between the ages of 51 and 84 years from START to NORTH corresponding to an increase in phonetic closeness and rounding with increasing age. The evidence for this is partially supported in two ways. Firstly, an increase in lip-rounding, which causes the vocal tract to lengthen, should result in a decrease in the first two formant frequencies (Lindblom & Sundberg 1971). Indeed both log. F1 ($R^2 = 0.37$, $F[1,142] = 85.7$, $p < 0.001$) and log. F2 ($R^2 = 0.24$, $F[1,142] = 46.5$, $p < 0.001$) decrease significantly and linearly with increasing age. The decrease in F1 might be enhanced because of an additional increase in

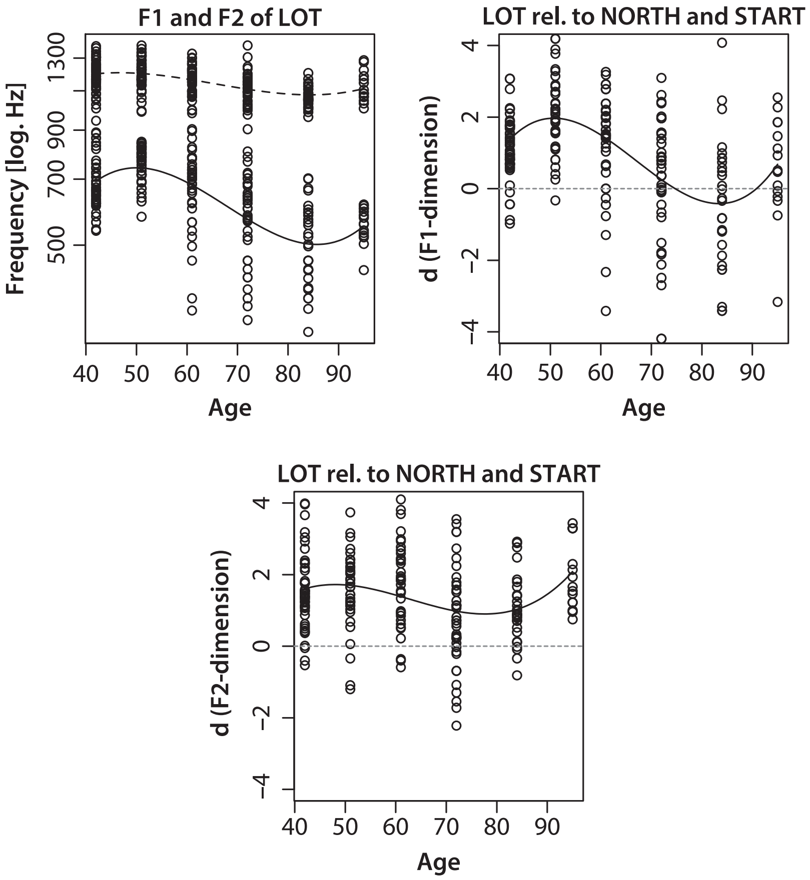

Figure 6. Left panel: F1 and F2 in LOT vowels as functions of age. Right panel: The log. Euclidean distance ratio in the F1 dimension for LOT related to the anchors NORTH and START as a function of age. Regression curves are superimposed

phonetic vowel height. The evidence that LOT shifts increasingly towards NORTH from START is shown by the significant decrease of *d* with age in F1 ($R^2 = 0.23$, $F[1,142] = 44.5$, $p < 0.001$) but not in F2.

THOUGHT Our prediction was that THOUGHT should also shift from START to NORTH due to increased closeness and greater lip-rounding. The evidence that it does so is firstly that there is a significant decrease both in F2 between 1950 and 2004 ($R^2 = 0.43$. $F[3,96] = 26.7$, $p < 0.001$) and in F1 from the age of 50 until the age of approximately 80, with a less pronounced subsequent increase ($R^2 = 0.43$, $F[3,96] = 26.2$, $p < 0.001$, Figure 7, left panel); and secondly that THOUGHT shifts towards NORTH and away from START, but only in F1 and only during the first three decades ($R^2 = 0.15$, $F[3,96] = 6.9$, $p < 0.001$, Figure 7, right panel).

DRESS Our prediction that DRESS shifts away from TRAP towards KIT was also supported by the data showing that between 1960 and 1993 there was a significant lowering of F1 ($R^2 = 0.39$, $F[3,297] = 65.9$, $p < 0.001$, Figure 8, left panel). This decrease was most marked between 1970 and 1981. The further analysis showed that DRESS was proportionately closer to KIT than to TRAP with increasing age on F1 ($R^2 = 0.28$, $F[3,297] = 40.4$, $p < 0.001$, Figure 8, right panel).

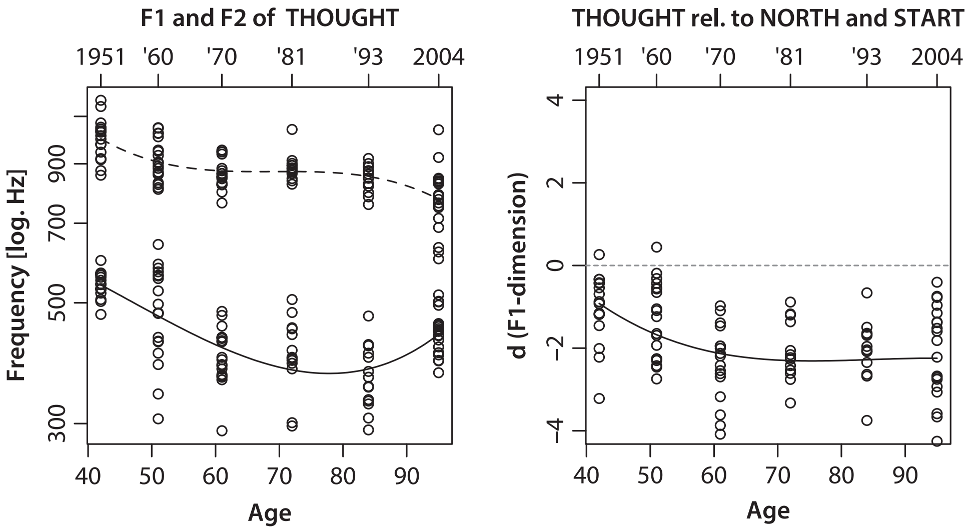

Figure 7. Left panel: F1 and F2 in THOUGHT vowels as functions of age. Right panel: The log. Euclidean distance ratio in the F1 dimension for THOUGHT related to the anchors NORTH and START as a function of age. Regression curves are superimposed

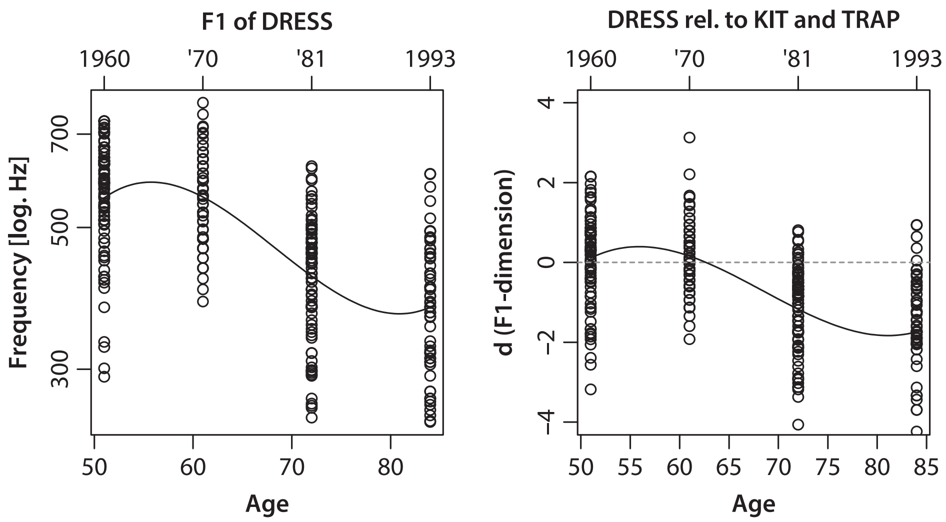

Figure 8. Left panel: F1 in DRESS vowels as a function of age (range 51–84 years). Right panel: The log. Euclidean distance ratio in the F1 dimension for DRESS relative to KIT and TRAP as a function of age. Regression curves are superimposed

8.3 Discussion

In this experiment, we tested whether our descriptive analysis of phonetic changes to Cooke's vowels could be quantified independently of age-related physiological changes. For this purpose, we calculated the relative distances of tokens of certain vowel types between two phonetically stable anchor vowels. The results of this analysis showed phonetic changes that were consistent with our auditory impressions of a shift in pronunciation from a General American variety towards forms more typical of British English Received Pronunciation over the period 1950–1980. The changes included in particular a backing of BATH, a raising and unrounding of LOT, and a raising of both THOUGHT and DRESS. The measure that we used, the log. Euclidean distance ratio, was shown to be insensitive to physiologically-induced formant changes. Thus, although F1 in THOUGHT was U-shaped (and therefore similar to F1 in other non-low vowels, as had been shown in Experiment I above), we perceived only changes in phonetic height towards a phonetically closer position in the vowel space, and our algorithm also registered only a convergence towards the closer anchor NORTH: this finding shows that the log. Euclidean distance ratio tracks phonetic changes independently of non-phonetic, physiologically induced changes to the formants. These results show that the log. Euclidean distance ratio normalizes for age-related changes to the acoustic vowel space and that the quantification over time using this metric matches our impressionistic description of phonetically changing vowels quite well. It seems to be useful not only for relatively large changes observed for BATH but also for the quantification of very subtle phonetic changes such as the raising of DRESS. Of course, there is still the possibility that the log. Euclidean distance ratio might remove phonetic effects. For example, the metric factored out F2-lowering in LOT and THOUGHT based on the data that show longitudinally a decrease in F2 with increasing age in these vowels. However, part of this lowering might also characterize a phonetic shift in Cooke's speech towards phonetically more raised vowels that have been noted as characteristic of the differences between GenAm and RP (Wells 1982). Beyond this consideration, the measure is dependent on assumptions about vowel types that phonetically change and other vowel types that remain phonetically stable. Therefore, this methodology depends crucially on a preceding definition of phonetic changes which must be derived from a descriptive analysis.

The results presented here do support our descriptive analysis of phonetic changes to Cooke's vowels, i.e. an accent shift from near GenAm to near RP. Given Cooke's biographical facts, this would suggest a reversion of his accent towards one acquired in England in Cooke's childhood/youth before he emigrated to America. This is rather a surprise, as consistently with accommodation theory (Giles, Coupland & Coupland 1991; Garrod & Pickering 2009), we expected Cooke to adapt his former accent towards an 'American' accent in the years after his relocation to the U.S., and for this 'American' accent to stabilize in later years. But our expectations do not apply to the longitudinal data in Cooke.

Howell, Barry & Vinson (2006) is to our knowledge the only phonetic study that has been concerned with shifts towards an earlier acquired accent; however, in their study, accent reversion was elicited by presenting speakers with frequency shifted or delayed auditory feedback. They conclude that "speech systems of speakers who have lost their accent are more vulnerable than those of speakers who have not changed their original accent" (Howell, Barry & Vinson 2006: 139). Cooke would fall into that "more vulnerable" group, but we do not have any evidence that Cooke suffered from a hearing impairment that would probably be the nearest 'natural' equivalent to the degraded auditory feedback that Howell, Barry & Vinson (2006) used.

Irrespective of any form of degraded auditory feedback, there is also other evidence from bilingualism studies for accent reversion, i.e. a reappearance of a 'foreign accent' in L2 due to e.g. cognitive impairments (Roth et al. 1997; Prescher 2007; Mariën et al. 2013). There are also other reports on losses in fluency in L2, increased code-switching, and other degradations of performance in L2 even in healthy older migrants (De Bot & Clyne 1989; Clyne 2011; Keijzer 2011). Therefore, an accent reversion as in Cooke's case does not seem to be implausible.

9. Summary and conclusions

Experiments I and II concerned age-related changes to formant frequencies in vowels that were judged to be phonetically constant with the passage of time. A summary of the findings in these two experiments is as follows:

a. F1 tracked f0 for vowels in which F1 is low in frequency and therefore close to f0. For this speaker, both f0 and F1 exhibited a falling-rising pattern with increasing age such that both parameters decreased roughly over 30 years up to the age of 72, and then increased up to the age 95. Such a pattern was evident for all non-low vowels (i.e. all vowels except for TRAP, STRUT, START). This tight association between f0 and F1 was especially evident for the high vowels FLEECE and GOOSE, for which f0 and F1 are closest together in frequency.
b. As far as TRAP, STRUT, and START are concerned, the age-dependent pattern of F1-change was opposite in direction to that of f0: for these vowels, there was an increase in F1 over 30 years up to the age of 72, and then a (more pronounced) decrease with increasing age thereafter.
c. F2 showed the same kind of pattern as in b. for STRUT and START but not for any other vowels.

The first and third findings are consistent with theories suggesting that frequencies falling within a band of 3.5 Bark are integrated (Chistovich & Lublinskaya 1979). Under this interpretation, f0 and F1 are perceptually integrated primarily in high vowels such as FLEECE and GOOSE in which F1 is low in frequency. Thus, our suggestion is that f0 falls (and then rises) with increasing age for physiological reasons, and F1 tracks f0 for perceptual reasons in order to keep the difference between F1 and f0 within 3.5 Bark for these high vowels. That is, the changes in a. are a *perceptual* readjustment to a *physiologically*-induced change to the fundamental frequency with increasing age. The third finding (c) is also consistent with this auditory integration theory: that is, our interpretation of the third finding is that F2 tracks F1 for those (back) vowels in which F2-F1 < 3.5 Bark. This condition is met for the present speaker primarily for the open back vowels in the START and STRUT Lexical Sets. It does not apply to the high back vowels in GOOSE and FOOT for which the first two formant frequencies are separated by more than 3.5 Bark. Thus our interpretation of this age-dependent F2 shift is once again perceptual: if F1 changes with increasing age, then so too will F2 for vowels for which the two formants are close in frequency in order to maintain F2-F1 < 3.5 Bark as a salient cue for phonetically back vowels.

We now need to reconcile finding c. with finding b. above that F1 generally seems to be a mirror-image to that of f0 with increasing age in the open vowels STRUT, START, and TRAP. The reason why F1 rises over a twenty-year span from 42 to 61 years of age is not entirely clear, but we have suggested that it might be some form of hyperarticulation that is the consequence of speaking more clearly (i.e. of a targeted increased mouth-opening resulting in the emission of greater acoustic energy in these open vowels). We can only speculate that this effect may be due to an increase in Cooke's professionalism as a radio commentator. The subsequent F1-decrease in these open vowels is very probably the result of an age-related change to the physiology often noted in elderly speakers, i.e. slower movements and atrophy of the muscles that are needed for the opening movement of the jaw, especially the lateral pterygoid and the digastric muscles (Linville & Rens 2001: 60–62; Monemi, Thornell & Eriksson 1999; Mioche et al. 2004). Thus the decrease in F1 in old age for START, STRUT, and TRAP (see also Liss, Weismer & Rosenbek 1990; Rastatter & Jacques 1990) might be a consequence of age-related changes to the vocal tract: as the jaw movements become slower and the muscles atrophy, it becomes more difficult in older age to attain a wide mouth opening in low vowels, leading to a decrease in F1. Whatever the causes of the F1-changes (hyperarticulation in earlier years, muscle atrophy in later years), our results suggest that F2 changes in unison with F1 in vowels like START and STRUT for which F2-F1 < 3.5 Bark. This covariation of F1 and F2 may then be a readjustment to guarantee the perceived backness of these vowels with increasing age. A further test of this theory would require analyzing the high back vowel [u] longitudinally in languages like French and German for which the quality is close to cardinal vowel 8 and as a result of which the first two formant frequencies are very close together in frequency.

Experiment III was concerned with longitudinal phonetic changes. Here we found evidence for phonetic changes in several vowels over roughly a 30-year period from 1950 in which Cooke shifted his accent from near General American to near Southern British English Received Pronunciation. These changes affected BATH (from [æ] to [ɑː]), LOT ([ɑ] to [ɒ]), THOUGHT and DRESS (both slightly increased in vowel height throughout the passage of time). This would suggest a reversion of his accent towards one acquired in England in Cooke's childhood/youth before he emigrated to America. There is, however, a caveat in this interpretation. Cooke was born in the north of England (near Salford) into a working class family and so is likely in his childhood to have had an accent more typically associated with the north of England, with possibly some Irish influences from his mother. However, he studied in Cambridge and so we are assuming (although cannot verify) that there was some pressure in his student days to shift his northern accent towards RP. Even today, students from the north of England attending a university in the south of England tend to change their accent to a more standard-like one (Evans & Iverson 2007) and we assume that this pressure to modify a northern accent towards RP would have been far greater in the 1920s when Cooke attended university. Thus, our evidence for a reversion to a former accent is based on the assumption that Cooke's accent between 1950 and 1980 has reverted towards one that characterized his accent when he left university and emigrated to America permanently in 1937.

In 1950, his accent has unmistakable characteristics of General American. This shift from 1932 to around 1950 towards General American is likely to have come about for reasons of accommodation (Giles, Coupland & Coupland 1991; Garrod & Pickering 2009): between 1937 and 1950, Cooke travelled extensively around the United States for professional reasons (Clarke 2000). It is because Cooke was exposed to so many American varieties in this period that his accent is likely to have adopted General American characteristics rather than attributes of a New York variety where he was resident (and we did not detect any New York characteristics in his 1950s broadcasts). Thus, consistent with both theories of accommodation (Giles, Coupland & Coupland 1991; Garrod & Pickering 2009) and more recent empirical studies (Pardo 2006, 2013; Pardo et al. 2012) showing that speakers converge towards phonetic characteristics of their interlocutors, Cooke adopted many attributes of General American over this time period because he interacted in conversation extensively with speakers of numerous American varieties during this period up to 1950.

The reasons for Cooke shifting from General American back towards RP are somewhat less clear. One of the earliest observations that older speakers revert to the accent they first acquired in childhood is in Wright (1905). Compatibly, Howell, Barry & Vinson (2006) found accent reversions when speakers were presented with degraded auditory feedback while speaking. There is also evidence from bilingualism studies for accent reversion: Prescher (2007) reports that the first language (L1) gains dominance over the second language (L2) in conditions like fatigue even for long-term migrants; and both Roth et al. (1997) and Mariën et al. (2013) report reversions to L1-influenced accents in formerly accent-free L2 speakers after several forms of brain damage. A widely held assumption in the bilingualism field is that even among healthy elderly migrants that stay in the L2 community, second language attrition and first language reversion are not uncommon. For example, De Bot & Clyne (1989) found that bilingual migrants became less fluent in their second language (L2) with increasing age, and tended to use code-switching more often later in life. This effect might come about because of reduced cognitive control and linguistic performance that is related to 'normal', healthy aging (Keijzer 2011), or might simply be due to reduced contact with speakers of L2, e.g. after retirement, and increased use of L1 in private (de Bot & Clyne 1989) – therefore this effect of L1 reversion and L2 attrition might not be inevitable (Clyne 2011).

We have no clear evidence as to whether Cooke had less contact with his local American environment beyond the age of 70 years, i.e. in the period when he shifted his accent towards RP. Some reduction in everyday contact to U.S. locals is possible, and there is at least evidence that he reduced the number of travels in later years (Clarke 2000). At the same time, the evidence that he did not retire and instead continued his broadcast until shortly before his death at 95 years of age make explanations couched in terms of any of the aforementioned age-related reductions in cognitive and linguistic performance unlikely.

There is documented evidence of style shifting towards the audience being addressed, e.g. in the speech of talk show host Oprah Winfrey (Hay, Jannedy & Mendoza-Denton 1999, 2010; cf. also Giles & Coupland 1991; Pickering & Garrod 2004). However, style shifting in the *Letter from America* broadcasts cannot explain why a shift towards RP should have taken place only after 1950. In his first years in the U.S., Cooke's motivation to be integrated as a member of American society was certainly very high (soon after his arrival he applied for U.S. citizenship), so this factor might have contributed to a rapid accent shift towards General American. Later on, he recognized that he had remained the "archetypal Englishman" (Clarke 2000: 1) for most of the American public, instead of being accepted as an American.

Additionally, Cooke's attitude towards the American society that had hosted him and in which he lived in did not remain as positive as it had been in earlier years, and his view of his own bicultural identity obviously changed:

> …there is at least some anecdotal evidence that, with the passing years, this gradual disenchantment made Cooke *feel* less American. He would tell interviewers that, as a younger man, he felt '110% American' (or even more). By the 1980s, he was occasionally caught referring to his fellow-citizens, in private, as 'they' rather than 'we'. This entailed not so much a nostalgia for Britain, but rather a sense of detachment from the America of Carter, Reagan or Clinton. By 1994 he was quoted as saying, 'I'm still an Englishman in America. An Irish Lancastrian, really, that's what I am. I don't kid myself that I'm from Arkansas.'
> (Clarke 2000: 591)

In conclusion, we have found both age-related and phonetic changes in broadcasts spanning 60 years by Alistair Cooke. The age-related changes are brought about by a declining fundamental frequency which in turn influences the first formant in high vowels: consistent with Reubold, Harrington & Kleber (2010), we have suggested that these similar shifts in the fundamental and first formant frequency are likely to have a perceptual origin. There are also F1 changes in low vowels that go in a different direction from those of high vowels. Here we have suggested that such changes are unlikely to be linked to changes in pitch given that f0 and F1 are well separated and therefore less likely to interact with each other in low vowels; the observed F1-lowering in low vowels may instead by related to muscular atrophy leading to a greater difficulty in obtaining as wide a mouth opening with increased age. The phonetic changes that we have observed involve a shift of accent from General American towards Received Pronunciation over a thirty-year period. The source of this change may be that Cooke came into less contact with speakers of General American in his later years of life, and he seems to have shifted his attitude towards the American society. Our study showing accent reversion in Cooke is consistent with studies in other areas such as bilingualism that provide some limited evidence for accent reversion later in life.

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