FOOT-fronting and FOOT–STRUT splitting: vowel variation in the East Midlands[1]

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This article investigates the status of the FOOT–STRUT split in the counties of Leicestershire, Nottinghamshire and Derbyshire in the East Midlands of England. The East Midlands area is a linguistic transition zone between northern English varieties with a phoneme inventory of five short vowels, where FOOT and STRUT are represented by the same phoneme, and southern English varieties which have the FOOT–STRUT split and therefore six short vowels. However, a lack of research on the distribution of the FOOT and STRUT vowels in the East Midlands exists and to fill that gap, this article examines the possible diffusion of the split northwards as predicted by Trudgill (1986). Reading-passage data, stratified by age group, sex and location is used to provide an apparent time, multilocal view on the distribution of the two vowel categories. Surprisingly, the changes that we notice do not concern the increasing distance between FOOT and STRUT but mainly FOOT-fronting in Leicestershire and Nottinghamshire and STRUT-retraction in Derbyshire which leads to an increase in overlap between FOOT and STRUT in all three counties.

Keywords: FOOT, STRUT, phonemic split, East Midlands, southern English, northern English, FOOT-fronting

1   Introduction

One of the main distinguishing features between contemporary northern and southern UK English varieties is the difference in the short vowel system (Trudgill 1986: 58–9; Hughes, Trudgill & Watt 2005: 59). While northerners have the same phoneme /ʊ/ for the lexical sets FOOT and STRUT, southerners distinguish /ʊ/ and /ʌ/ for FOOT and STRUT (Wells 1982b: 337), i.e. for northerners the words *putt* and *put* are homophones while southerners pronounce these words differently.

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Middle English showed no such distinction (Wells 1982a: 196) and this split is a relatively recent change which started in the seventeenth century in London in which 'ME ŭ, phonetically [ʊ], developed an unrounded variant, [ʌ], in certain words' (Chambers & Trudgill 1998: 106; Beal 2008: 131). Wells (1982a), Harris (1996) and Turton & Baranowski (2020) provide an overview of the different stages of the FOOT– STRUT split. Beal comments that the development of the FOOT–STRUT split could be described as change from below and that the lack of the split may not have been recognised as a 'shibboleth of northern speech' until the middle of the eighteenth century (Wales 2006: 103; Beal 2012b: 8, 131).

Disagreement exists about the exact geographical distribution of the FOOT–STRUT isogloss; Wells (1982a: 197), for example, comments that the split has not taken place 'in broad accents of the north of England' and that 'we cross from the south to the linguistic north at the point where we pass the northern limits (in broad local accents) of the FOOT–STRUT Split and of BATH Broadening' (Wells 1982b: 349). Upton & Widdowson (1996: 27) comment that it distinguishes 'Northern and North Midland speakers from those of the South and South Midlands', while Clark (2008) states that the FOOT–STRUT isogloss clearly runs to the South of the West Midlands. In all cases, this isogloss runs near to the East Midlands, making it of linguistic interest as this region is often described as a transition zone between the north and the south (Trudgill 1986; Chambers & Trudgill 1998). Drummond (2012: 71) comments that there is variation of the STRUT vowel in the north, particularly for those higher up the social classes, where it can be found to be intermediate between the FOOT and STRUT vowel. Wells classifies 'northern' as 'midlands and northern' (Wells 1982b: 349) but also classifies the linguistic north as everything north of the Severn–Wash line (Wells 1982b: 350) and states that this line is the isogloss for the FOOT–STRUT split (Wells 1982b: 351).

The East Midlands is often underrepresented in research on linguistic variation and seems to be a linguistic no-man's land (Upton 2012: 258). Several studies and descriptions miss out the region altogether (e.g. Britain 2007; Kortmann & Upton 2008; Ferragne & Pellegrino 2010). Upton comments that this region 'might be thought to warrant attention in its own right rather than being thought of as a mere junction between contrasting varieties' (Upton 2012: 262). Only recently have sociolinguists started to cover this area, e.g. Flynn (2012), Braber (2014, 2015), Braber & Flynn (2015) and Braber & Robinson (2018). In other areas of the country, which are also part of the transition zone between the north and the south, the FOOT–STRUT split has been investigated in more detail, e.g. Chambers & Trudgill in East Anglia (1998) and Britain in the Fens (1991, 2002).

In addition to the northern and southern forms, Chambers & Trudgill (1998: 110–13; see also Trudgill 1983: 49–51; 1986: 59–62; Upton 1995, 2012) differentiate between *mixed lects* and *fudged lects* in the transition zone between the north and the south. Speakers are said to use mixed lects when their pronunciation varies between [ʊ] and [ʌ] and fudged lects when they produce 'a phonetic compromise' (Hughes *et al.* 2005: 60) transcribed as [ɤ] (Trudgill 1986; Chambers & Trudgill 1998) or [ə] for STRUT

(Beal 2010: 13; see also Braber & Flynn 2015: 384). Therefore, the use of the lowered variant is not an indicator for a phonemic split between FOOT and STRUT.

Wells (1982a: 132, 196–9; 1982b: 351–3) states that the FOOT–STRUT split is generally not found in the Midlands but that some speakers may show intermediate stages where the STRUT vowel produced may be perceptually different from both [ʊ] and [ʌ] or a hypercorrect avoidance of [ʊ] in FOOT words. Docherty & Foulkes (1999) claim that STRUT is /ʊ/ in Derby but may be realised as [ə] in more self-conscious speech styles, particularly by women. Hughes *et al.* (2005: 71) describe the split only for the South Midlands, while the north-west Midlands, East Midlands and West Midlands do not have the distinction between FOOT and STRUT. The discussion of their representative Leicester speaker shows that this speaker has no distinction between *put* and *putt*, both are realised with [ʊ] (Hughes *et al.* 2005: 91). They speculate that due to the influence of RP many northern English speakers have a STRUT vowel between /ʊ/ and /ʌ/ which is schwa like (Hughes *et al.* 2005: 60). Trudgill (1986: 59) claims that the six short vowel system and therefore the phonemic split between FOOT and STRUT is gradually diffusing northwards at the cost of the five short vowel system. Recent dialectological accounts such the *English Dialect App* data (see Leemann *et al.* 2018) and *Mapping variation in English in the UK* (MacKenzie *et al.* 2014) reveal that this might be the case, but the results are based on a very limited data set of lexical items and the data are skewed towards younger speakers.

Very few sociophonetic studies concerning the FOOT–STRUT split in the transition zone have been conducted so far. Based on single-speaker measurements, Ferragne & Pellegrino (2010: 9f.) report the split for Birmingham in the West Midlands. Turton & Baranowski (2020) conduct a variationist study in Manchester and focus on the distribution of FOOT and STRUT according to social class. They conclude that only very few people, mainly belonging to the highest social class, have the phonemic distinction between FOOT and STRUT. An initial account of FOOT–STRUT variation in the East Midlands is provided by Braber & Flynn (2015: 384). They state that for a number of speakers variation in STRUT exists between /ʊ/ and /ʌ/, as the vowel produced is not [ʌ] but has a more central, schwa-like quality. They also suggest that 'this is an area that warrants further exploration to add to the small amount of existing research on FOOT/STRUT distinction in the area in close proximity to the FOOT–STRUT isogloss' (Braber & Flynn 2015: 386). Many of the studies seem to rely on phonetic distinction between the vowels to distinguish the status of the two phonemes, while Turton & Baranowski (2020) argue that even speakers who show a phonetic difference between the two lexical sets due to co-articulation with adjacent segments might not have the split. Rather, they may simply show the phonetic precursor to the split, replicating the pattern that those in the south would have had before the split was innovated.

In terms of present-day perception, the lack of the split seems to be very salient to southerners but less so for northerners. Beal claims that the lack of the split is not salient to those who do not have the split, although it is frequently stigmatised by those who do have it (Beal 2012a: 70; 2012b: 7, 12–13). Wells argues that 'Many educated northerners … would not be caught dead doing something so vulgar as to pronounce

STRUT words with [ʊ]' (Wells 1982b: 354) and Wales (2006: 210) comments that the northern /ʊ/ is likely to remain an important and salient marker in the north. The lack of the split is enregistered in certain phrases, e.g. *oop north* or *fook* (Beal 2012b: 6).

The previous discussion highlights the need for a more detailed investigation of the distribution of FOOT–STRUT in the East Midlands. In this article we therefore provide a multilocal analysis of it in order to explore the occurrence of the FOOT–STRUT split in three counties of the East Midlands: Leicestershire, Nottinghamshire and Derbyshire.

Furthermore, investigating the variation and change in the FOOT–STRUT split has theoretical implications in that the spread of the distinction between FOOT and STRUT means that speakers need to acquire a new phonemic category. Nycz (2018) discusses the acquisition of splits in the context of Canadians who moved to New York and acquired parts of the LOT/THOUGHT distinction. Mobile speakers are a good testing ground for the acquisition of splits. Nycz argues that speakers can acquire a small distinction due to gradual increase of the distinction in individual lexical items. She concludes that this situation does not result in a category-level split. Given the above description, the East Midlands is for that reason a good testing ground for the development of splits in the wild.

2   FOOT–STRUT in the SED, MMB and *BBC Voices* data

In order to provide a real-time perspective, three datasets held by the British Library are consulted here to establish the use of FOOT and STRUT in the East Midlands in the first half of the twentieth century: the *Survey of English Dialects* (SED, Orton *et al.* 1962–71); the *Millennium Memory Bank* (MMB) and *BBC Voices*. For the SED the informants were mainly non-mobile older rural men who were recorded in the 1950s. The MMB data were collected during 1998 and 1999, when forty BBC local radio stations recorded personal oral histories from a broad cross-section of the population. Interviews concentrated on everyday life. The *BBC Voices* project provided a snapshot of the language in the UK at the start of the twenty-first century. *BBC Voices* contains a set of group conversations about language, accent and dialect recorded in locations across the UK by BBC Local Radio in 2004 and 2005. These recordings are included in full on the British Library website, as well as metadata about the speakers, abstracts of the contents of the interviews and for some of them, linguistic descriptions of the recordings, including information about phonetic, lexical and morpho-syntactic features. These recordings were analysed auditorily by the British Library and also by the authors of this study. An overview of STRUT from the SED, MMB and *BBC Voices* data from the East Midlands can be found in table 1. We follow Foulkes & Docherty (1999) in the representation of the variants by organising them in order of quantity.

In the case of FOOT, there is relatively little to say as almost all speakers are using the expected [ʊ] variant with very little exception. Hence, we did not include this information in table 1. STRUT is mainly realised as [ʊ] and hardly any variation exists for the speakers in Nottinghamshire and Derbyshire in all three datasets. Speakers in Leicestershire, however, show more variation. There are examples of both [ʊ] and [ʌ]

Table 1. STRUT *in the SED, MMB and* BBC Voices *East Midlands recordings*

	SED	MMB	*BBC Voices*
Nottinghamshire	ʊ	ʊ	ʊ
Leicestershire	ʊ ~ ʌ ~ ɤ ~ ɒ	ʊ ~ ə	ʊ ~ ʌ ~ ə ~ ɵ
Derbyshire	ʊ	ʊ	ʊ ~ ɒ

as well as two occurrences of [ɤ], which implies the existence of a fudged vowel, and one of [ɒ], which appeared in the word 'mother'. It has been suggested (Jonnie Robinson, personal communication) that the second might be a relic of Middle English and can sometimes be found in the West Midlands (*mom* for *mum*, for example). This pronunciation has also been noted in Alan Sillitoe's literary works, for example *bugger* is spelt as *bogger* in *Saturday Night and Sunday Morning* (1958), which is set in Nottingham.

The increased variation in Leicestershire indicates that the five-vowel system seems slowly to be replacing the six-vowel system, as Trudgill (1986: 59) has predicted. At the same time, the lack of the split was a characteristic in the varieties of Nottinghamshire and Derbyshire in the three data sets stretching from the middle of the twentieth century to the first decade of the twenty-first century.

However, we do not know sociophonetic details about the status of the FOOT–STRUT split in the East Midlands in the second decade of the twenty-first century. Hence, this article addresses the following research questions:

1. What are the acoustic properties of FOOT and STRUT in the three counties? How much overlap exists between the variables?
2. What is the geographical and apparent time distribution of FOOT and STRUT in the three counties?
3. Is a diffusional pattern of the FOOT–STRUT split observable in the three counties?

3 Methodology

In order to address the research questions, we created a speech sample of 60 speakers, 20 speakers each from Leicestershire, Nottinghamshire and Derbyshire (see figure 1 and table 2). The sample has been stratified according to age, sex and place. Speakers in the older age category were over 55 years old, speakers in the younger age category were between 18 and 25 years old. Each speaker read a text passage (see Appendix 1) which contained 13 lexical items with STRUT vowels and 18 lexical items with FOOT vowels; the passage was then read a second time.

Recordings were conducted by the second author and students from Nottingham Trent University who were local to one of the three counties under study in this project. The people who carried out recordings were briefed thoroughly about recording conditions and placement of the recording device. The recordings were made on phones, recorded
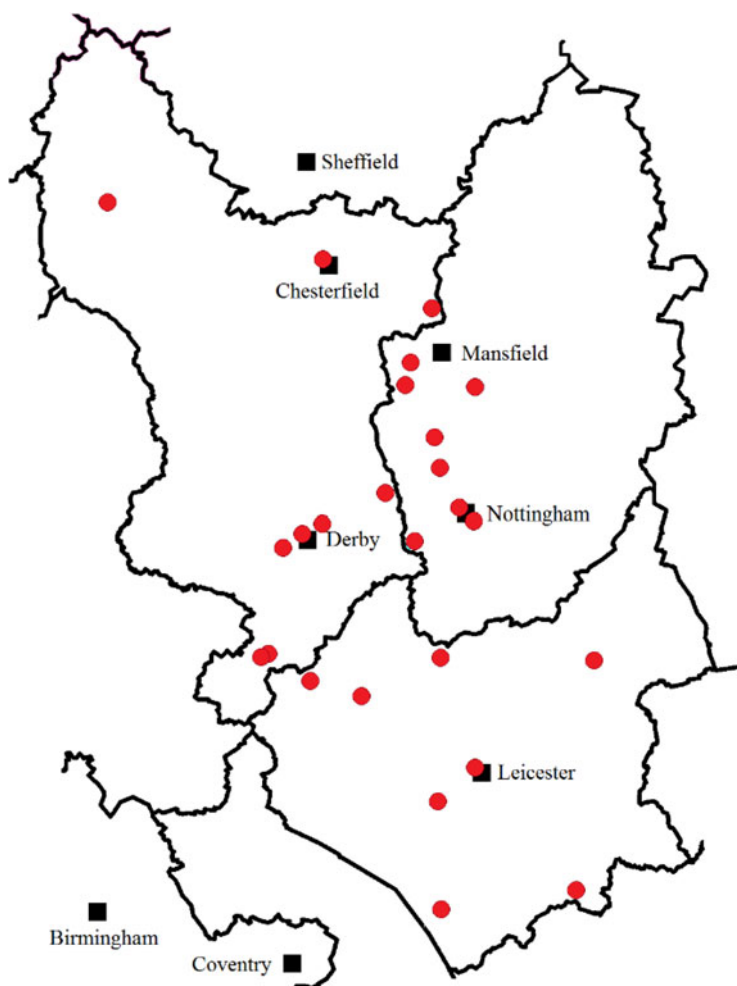
Figure 1. Map of East Midlands with speaker locations

in mp4 format, then converted to .wav with the Macbook converter. Each recording was

Table 2. *Speech sample stratified by age group, sex and county*

	Leicestershire		Nottinghamshire		Derbyshire	
	Young	Old	Young	Old	Young	Old
M	5	5	5	5	5	5
F	5	5	5	5	5	5
Total	10	10	10	10	10	10

auditorily checked for quality by the first author. After that the recordings were transcribed in ELAN (Sloetjes and Wittenburg 2008).

The sound files were subjected to forced alignment of segments with *FAVEalign* (Rosenfelder *et al.* 2011), an automatic alignment tool adapted for sociolinguistic research. The program facilitates the automatic conversion of an orthographic transcription into phonemes by looking up words and their transcriptions in a pronunciation dictionary. Following the alignment, we used *FAVEextract* (Rosenfelder *et al.* 2011), a program which allows the automatic extraction of formant measurements for a given speaker in an aligned sound file. This was used to extract all vowel tokens of the reading passage, which had a duration of at least 50 ms. These were measured at the midpoint and included in the analysis. Overall, 2,831 tokens were extracted, of which 1,111 belong to the STRUT set and 1,720 to the FOOT set. To compare vowel realisations between speakers, vowel measurements were normalised with *FAVE*'s built-in transformation based on Lobanov (1971).

4 Data analysis: overlap between FOOT and STRUT

In order to investigate the status of FOOT and STRUT, we decided to use overlap measurements. Different methods to measure the distribution of overlap exist. Johnson (2015) discusses alternative measures such as Euclidean distance (e.g. Herold 1990; Evanini 2009; Johnson 2010) and Pillai's trace (e.g. Hay *et al.* 2006; Nycz & Hall-Lew 2014), but explains that Bhattacharyya's Affinity (Bhattacharyya 1943) is preferable to these measurements because it is less sensitive to nested, crossed, skewed or imbalanced distributions, unlike Pillai scores (Johnson 2015). Bhattacharyya's Affinity measures overlap between two cohorts in a two-dimensional space, which makes it an ideal measurement for F1/F2 vowel distributions. Recent studies by Strelluf (2016, 2018), Stanley & Renwick (2016) and Warren (2018) use this measurement for overlap in vowel mergers.

Bhattacharyya's Affinity measures the overlap between two distributions on a scale from 0 to 1, generating a coefficient of 0 if no overlap exists between the two distributions and a coefficient of 1 for distributions which overlap completely, which is an advantage over Pillai scores. Bhattacharyya's Affinity is included in the {adehabitatHR} package for R (Calenge 2006; R Core Team 2015). However, unlike Pillai's trace, Bhattacharyya's Affinity does not return a significance score.

Figure 2 shows a scatterplot of FOOT and STRUT in the three counties. At first sight, the distribution between the different counties looks very similar, with the majority of FOOT and STRUT tokens overlapping but nevertheless not a complete overlap. Table 3 provides the overall Bhattacharyya's Affinity measurement for each county. The values confirm the large but not complete overlap between FOOT and STRUT in every county. As previously mentioned, Turton & Baranowski (2020) argue that speakers might not have the split, even though phonetic differences between the two lexical sets exist which are due to co-articulation with adjacent segments. Hence, a complete overlap with a value of 1 is not expected. On the other hand, the value can only provide
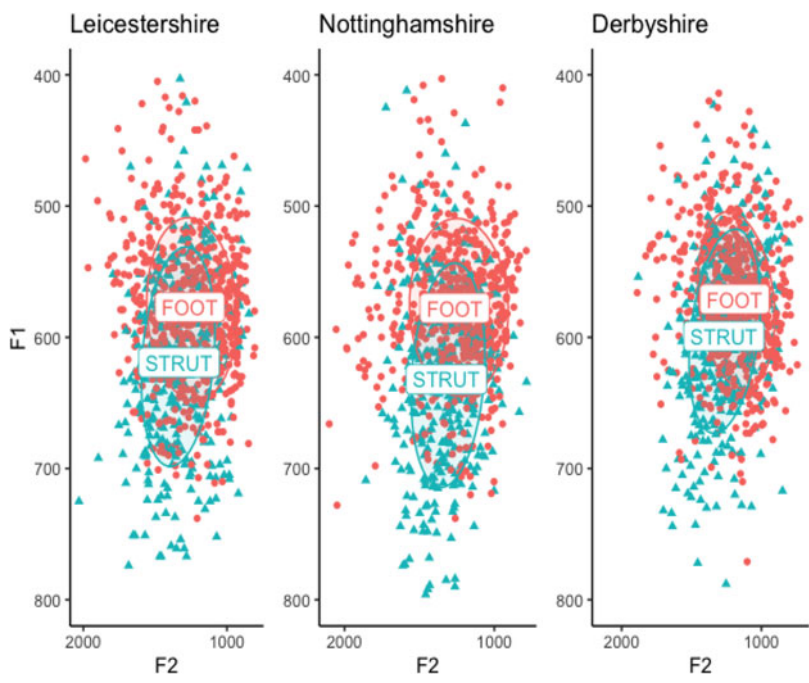
Figure 2. Overlap of FOOT and STRUT in Leicestershire, Nottinghamshire and Derbyshire

Table 3. *Bhattacharyya's Affinity for the three counties*

Overall	.92999
Derbyshire	.9444
Leicestershire	.9306
Nottinghamshire	.8987

information about the (changes in the) overlap, not whether the speakers have a phonemic split or not. However, a decrease in the overlap of FOOT and STRUT might hint at a phonemic split.

   The overlap in Derbyshire is higher than for Nottinghamshire and Leicestershire, and Nottinghamshire displays a lower overlap than Leicestershire, which comes as a surprise if we assume that the increase of the split (i.e. less overlap) is a northward movement. Welch's two-sample *t*-test of Bhattacharyya's Affinity for the three counties[2] returns a significant difference between Derbyshire and Nottinghamshire [p = .0363] but not between Derbyshire and Leicestershire [p =.209] and Leicestershire and Nottinghamshire [p = .3184].

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[2] Input to the *t*-test: Bhattacharyya's Affinity measurements for individuals as presented in tables 5, 6 and 7.

Table 4. *Bhattacharyya's Affinity for age groups in the different counties*

County	Old	Young
Derbyshire	.9158585	.9590346
Leicestershire	.8841179	.9497770
Nottinghamshire	.8501675	.9238492

What is surprising is that the overlap seems to be lower for older speakers than for younger speakers in the three counties (see table 4). This means that the overlap between FOOT and STRUT increases across apparent time. At first sight, this finding is contrary to Leemann *et al.*'s (2018) finding that the split is slowly expanding northwards.

Following this, the vowel distribution and overlap for each of the three counties was investigated separately. We started with the northernmost county, Derbyshire. Figure 3 presents the distribution of FOOT and STRUT in Derbyshire in scatterplots with the label representing the midpoint of both phonemes, which seem to move towards each other in apparent time, i.e. the vowel quality of both phonemes is more similar for younger speakers than for the older speaker group.

To gain a full picture in terms of individual variation, Bhattacharyya's Affinity for each speaker was calculated (see table 5), revealing that none of the speakers in the Derbyshire
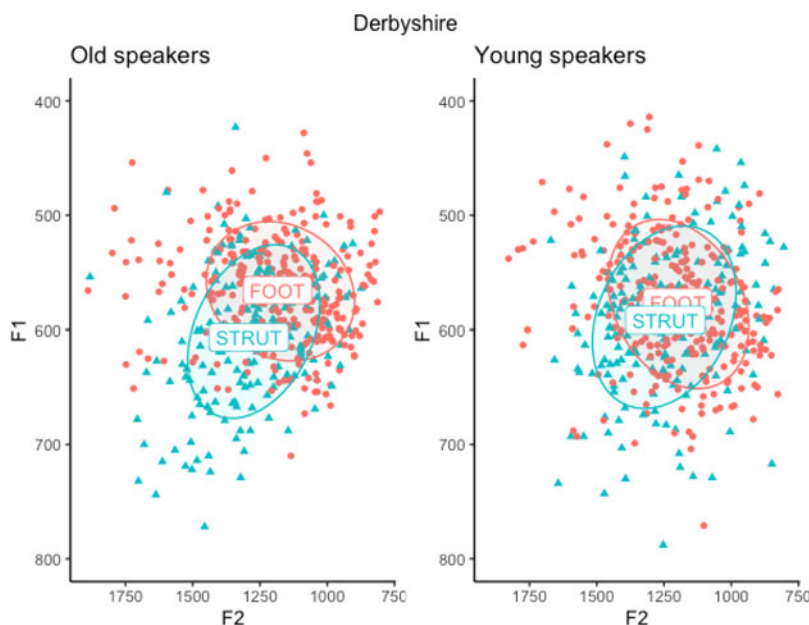

Figure 3. Overlap of FOOT and STRUT in Derbyshire according to age group; Old speakers: Bhattacharyya's Affinity .9165; Young speakers: Bhattacharyya's Affinity .9597

Table 5. *Bhattacharyya's Affinity (BA) for the individual speaker in the Derbyshire sample (Pseudonym coding: D = Derbyshire, O = old, Y = young, M = male, F = female)*

Speaker	BA	Speaker	BA	Speaker	BA	Speaker	BA
DOM1	0.8925133	DOF1	0.7628573	DYM1	0.9223414	DYF1	0.9313322
DOM2	0.9661883	DOF2	0.9022049	DYM2	0.90429	DYF2	0.9099797
DOM3	0.8968358	DOF3	0.8755241	DYM3	0.9413219	DYF3	0.8916205
DOM4	0.8591291	DOF4	0.8250768	DYM4	0.9519424	DYF4	0.9544982
DOM5	0.7658463	DOF5	0.9235225	DYM5	0.8878762	DYF5	0.9265126

sample shows a complete separation of FOOT and STRUT, which again could be explained by Turton & Baranowski's findings. Welch's two-sample *t*-test of Bhattacharyya's Affinity for the two age groups returns significant at p = 0.0293, i.e. a change in progress based on the degree of overlap is observable. Figure 4 displays the speakers with the highest Bhattacharyya's Affinity, which is DOM2 and the lowest Bhattacharyya's Affinity, which is DOF1 in the Derbyshire sample. Both speakers belong to the older group of speakers, which indicates that a high level of interspeaker variation exists for this age group.
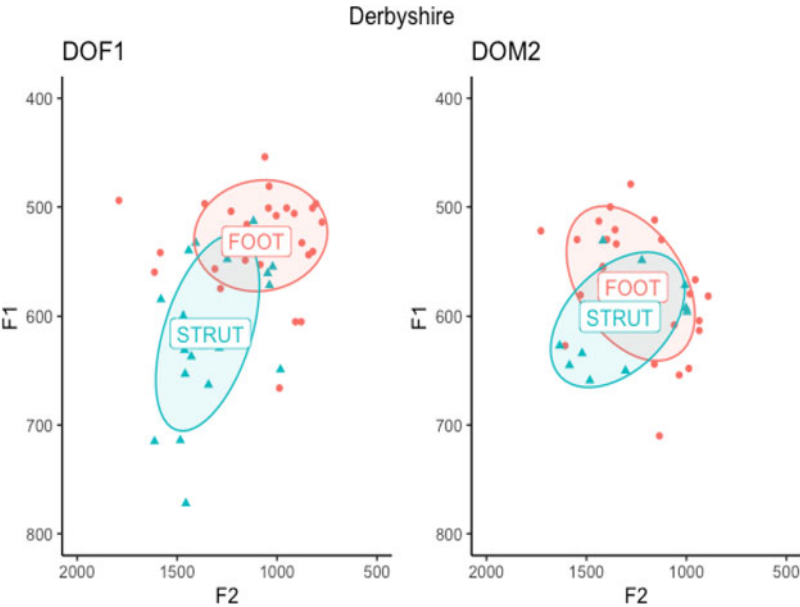

Figure 4. Derbyshire individual with the least overlap (left; Bhattacharyya's Affinity 0.7628573) and the most overlap (right; Bhattacharyya's Affinity 0.9661883)
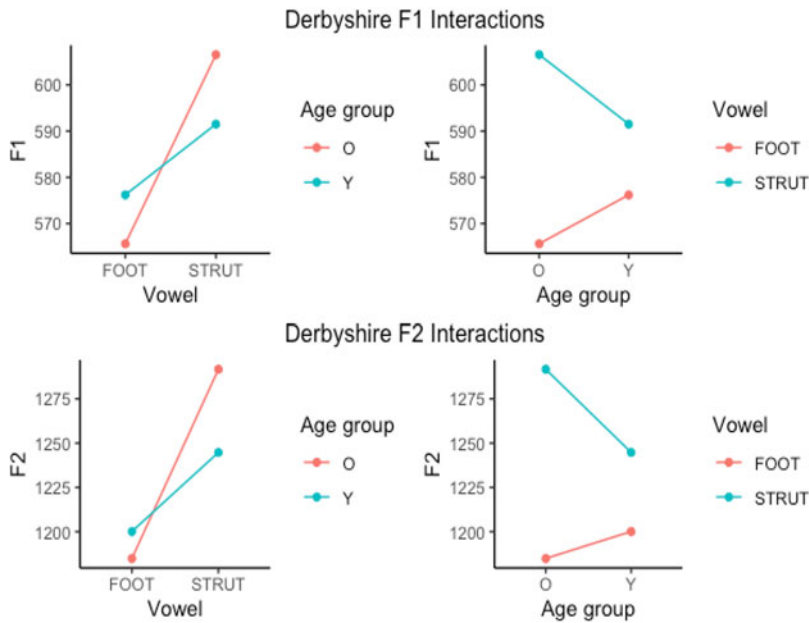
Figure 5. Interaction of vowel and age group for F1 and F2 in Derbyshire

Figure 5 provides the interactions for F1 (top) and F2 (bottom) in Derbyshire. Younger speakers have higher F1 values (i.e. lowering) for FOOT than older speakers. At the same time, F1 for STRUT decreases, i.e. the vowel is raised in apparent time. Furthermore, the average values for FOOT and STRUT also become more similar. There are also some changes observable for F2. The average F2 value for FOOT increases slightly, which means that FOOT is produced marginally further front by younger speakers than by older speakers. The average value does not vary to any great extent between younger and older speakers but we also see STRUT retracting in considerable measures.

In a similar pattern to Derbyshire, the Nottinghamshire dataset (see figure 6) illustrates an increased overlap between FOOT and STRUT; however, the Bhattacharyya's Affinity according to age group is not significant (Welch's *t*-test, p = 0.3603), i.e. the degree of overlap is not significantly different in apparent time. The Bhattacharyya's Affinity for the individual speakers reveals that there are three speakers who have a Bhattacharyya's Affinity score of lower than 0.7 (see table 6). Comparing these scores with the data from Derbyshire, only one speaker there has a score lower than 0.8, and all other speakers have a higher score. Hence, interspeaker variation is higher in Nottinghamshire and variation in the overlap of FOOT and STRUT seems to exist between these two counties.

Figure 7 provides detail about interspeaker variation in the Nottinghamshire data. While the older male speaker (NOM2) has a Bhattacharyya's Affinity of 0.5015224, the young male speaker (NYM5) has a very high overlap rate of 0.9636763. The changes in F1 for both vowels are fairly slim but the plots in figure 8 reveal that F2 is
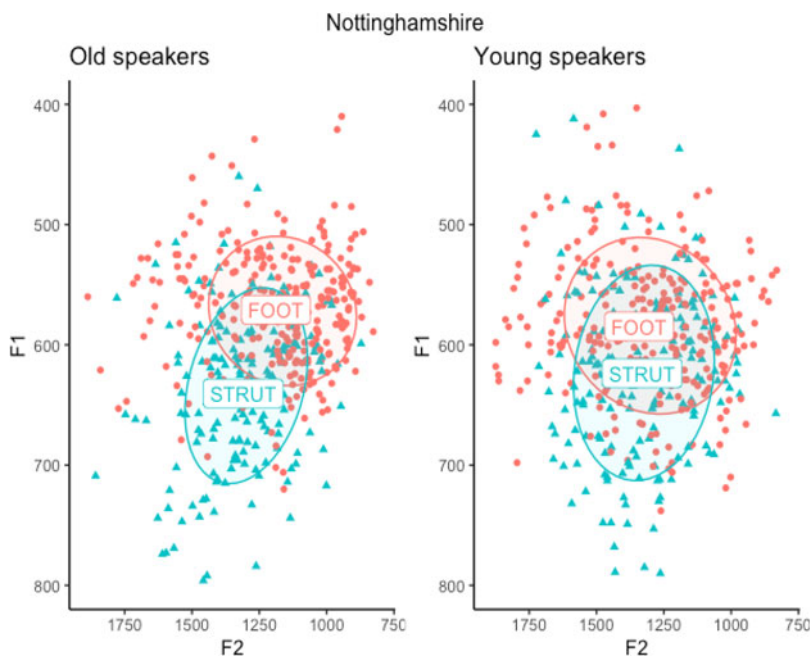
Figure 6. Overlap of FOOT and STRUT in Nottinghamshire according to age group; Old speakers:
Bhattacharyya's Affinity .8501675; Young speakers: Bhattacharyya's Affinity .9238492

Table 6. *Bhattacharyya's Affinity (BA) for the individual speaker in the
Nottinghamshire sample (Pseudonym coding: N = Nottinghamshire, O = old,
Y = young, M = male, F = female)*

Speaker	BA	Speaker	BA	Speaker	BA	Speaker	BA
NOM1	0.95234	NOF1	0.8272678	NYM1	0.8924713	NYF1	0.8924882
NOM2	0.5015224	NOF2	0.8791157	NYM2	0.5436345	NYF2	0.8873889
NOM3	0.8266961	NOF3	0.8810578	NYM3	0.8606689	NYF3	0.9441234
NOM4	0.813574	NOF4	0.662378	NYM4	0.8331135	NYF4	0.8222013
NOM5	0.9148425	NOF5	0.7438428	NYM5	0.9636763	NYF5	0.8924693

changing more in FOOT than in STRUT in apparent time. In fact, FOOT F2 increases quite
dramatically for the young speakers, i.e. FOOT is fronting in this setting. The young
speakers' FOOT F2 is partly even higher than for STRUT. The findings suggest that it is
not the case that FOOT is the anchor with STRUT changing, but that there seems to be
considerable movement in the FOOT vowel as well.

Coming to the Leicestershire data, again we see an increase of overlap between
FOOT and STRUT for the younger speakers compared to the older speakers (see figure

Figure 7. Nottinghamshire individual with the least overlap (left; Bhattacharyya's Affinity 0.5015224) and the most overlap (right; Bhattacharyya's Affinity 0.9636763)

9). Table 7 shows that only one speaker has a Bhattacharyya's Affinity of less than 0.7 and the speaker with the highest overlap score has a score of 0.9881098 (see figure 10), which means that the overlap between FOOT and STRUT is almost
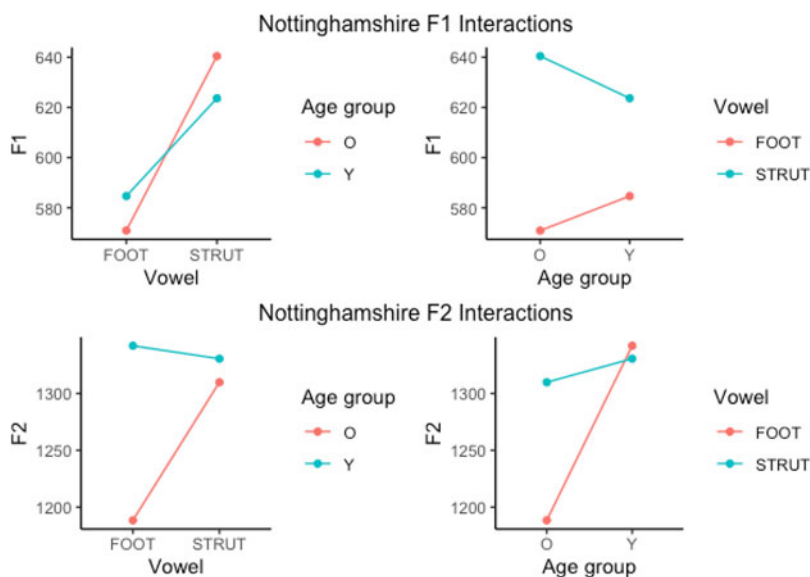
Figure 8. Interaction of vowel and age group for F1 and F2 in Nottinghamshire
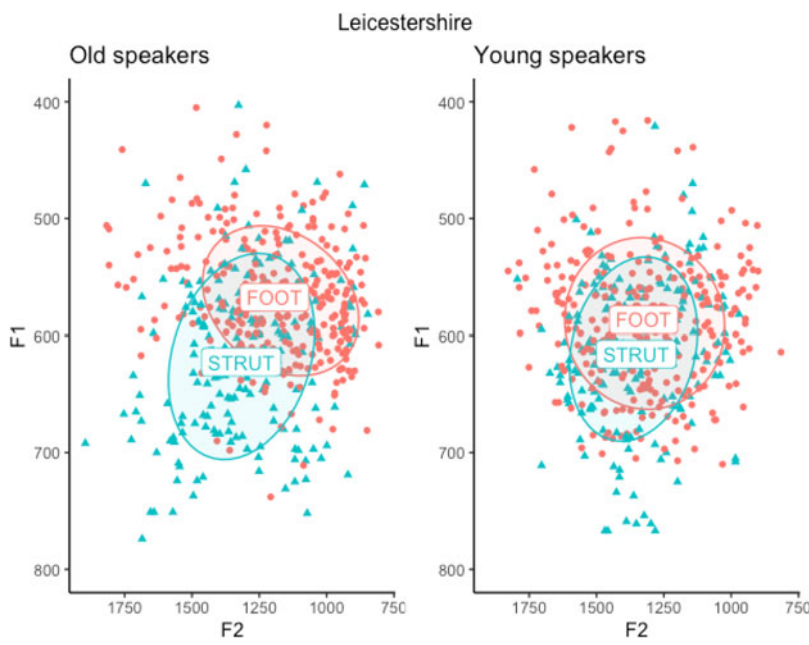
Figure 9. Overlap of FOOT and STRUT in Leicestershire according to age group; Old speakers: Bhattacharyya's Affinity 0.8841179; Young speakers: Bhattacharyya's Affinity 0.9497770

Table 7. *Bhattacharyya's Affinity (BA) for the individual speaker in the Leicestershire sample (Pseudonym coding: L = Leicestershire, O = old, Y = young, M = male, F = female)*

Speaker	BA	Speaker	BA	Speaker	BA	Speaker	BA
LOM1	0.8778542	LOF1	0.6559476	LYM1	0.8695134	LYF1	0.9666903
LOM2	0.7669219	LOF2	0.7568527	LYM2	0.918321	LYF2	0.9387908
LOM3	0.9562361	LOF3	0.7095721	LYM3	0.8696454	LYF3	0.7358457
LOM4	0.8699879	LOF4	0.7602974	LYM4	0.9397128	LYF4	0.8945513
LOM5	0.9394221	LOF5	0.916847	LYM5	0.9205675	LYF5	0.9881098

complete. Unlike in the other two counties, the difference in Bhattacharyya's Affinity between age groups is approaching significance at $p = 0.0538$. The increase in overlap is especially observable between the older and the younger women in table 7. Four out of five older women have an overlap measurement of around 0.7, while three younger women have a Bhattacharyya's Affinity higher than 0.9. If there is a tendency for STRUT to split from FOOT, the older (then younger) women in Leicestershire are probably the group who were the leading
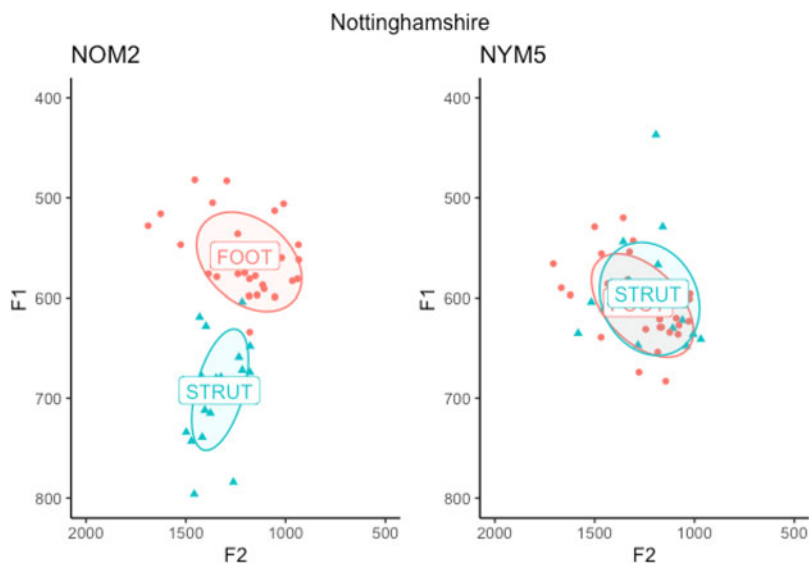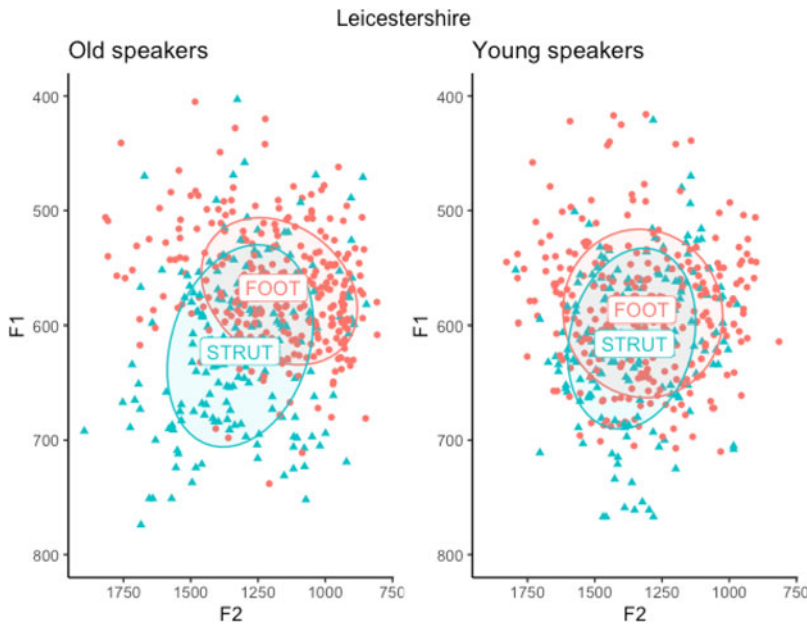
Figure 10. Leicestershire individual with the least overlap (left; Bhattacharyya's Affinity 0.6559476) and the most overlap (right; Bhattacharyya's Affinity 0.9881098)

agents of this change. Zooming in on sex differences in Leicestershire, figure 12 shows that F1 movement in STRUT does not vary much between older and younger women other than a decline in variation in this dataset, suggesting the split seems to have come to a halt while FOOT-fronting then drove the change towards an increase in overlap. While FOOT F2 in Nottingham is partly higher (i.e. fronter in the oral cavity) than STRUT F2 (figure 8), in Leicestershire FOOT F2 is approaching STRUT F2 across apparent time but is still realised further back than STRUT. Figure 12 also reveals that women are driving the change towards FOOT-fronting in Leicestershire.

Overall, the data provide details about interactions for F1 and F2 in the dataset. Figures 5, 8 and 11 illustrate the interaction of vowel and age group for F1 in Derbyshire, Nottinghamshire and Leicestershire respectively. In all three counties, the F1 values of FOOT and STRUT are converging to some extent in apparent time, i.e. F1 for STRUT is decreasing while F1 for FOOT is increasing.

Comparing the interactions for F2 between the three locations reveals a slightly more complex situation. In Leicestershire and Nottinghamshire F2 for STRUT is increasing slightly in apparent time. In Derbyshire on the other hand, we see a countermovement, i.e. the retraction of STRUT. FOOT F2 is increasing (i.e. FOOT is fronting) in all three counties albeit to different degrees. The least fronting occurs in Derbyshire, while a strong increase of F2 is observable for Nottinghamshire where FOOT is partly fronter than STRUT for young speakers.

Figure 11. Interaction of vowel and age group for F1 and F2 in Leicestershire

6 Statistical analysis

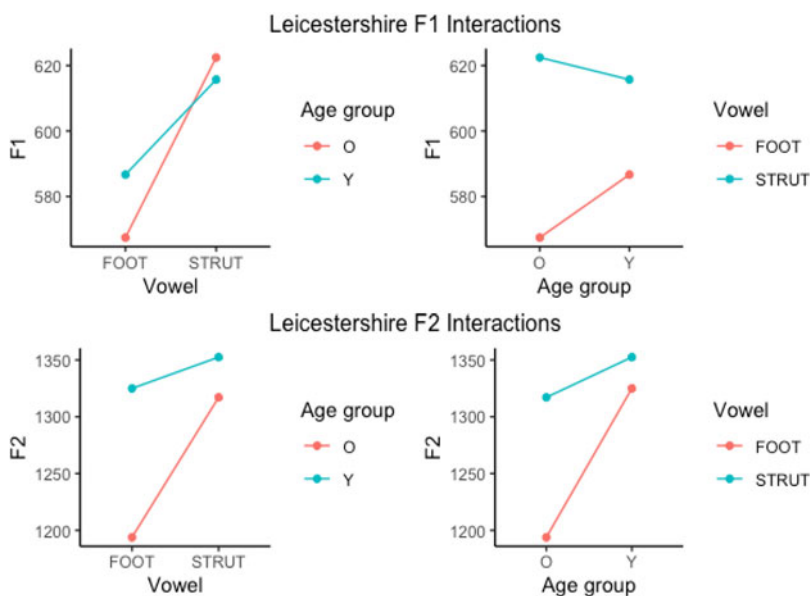In order to gain a more in-depth understanding of predictor strength as well as potential predictor interaction, a series of linear mixed-effects models was run to fit the best
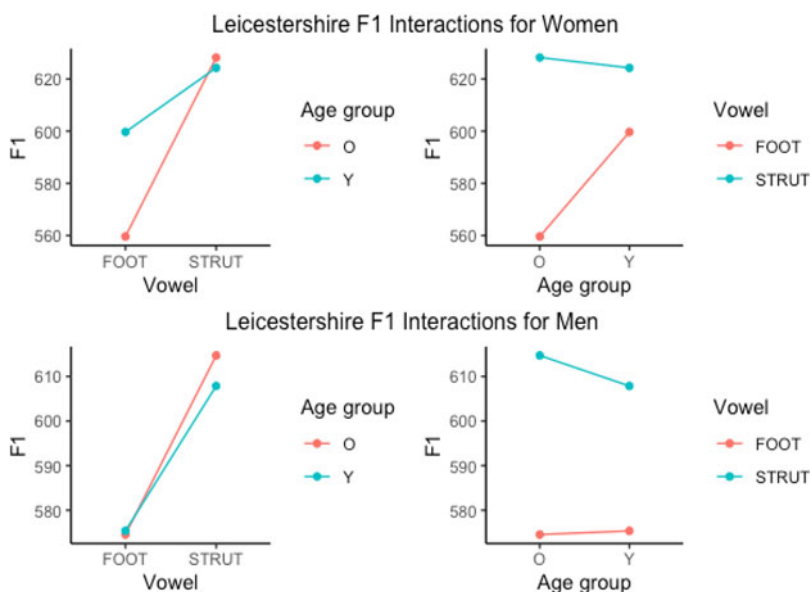

Figure 12. Interaction of vowel and age group for F1 and F2 in Leicestershire according to sex

Table 8. *Independent variables and factors in the statistical model*

Independent variables	Factors
vowel	FOOT/STRUT
county	Derbyshire, Leicestershire, Nottinghamshire
sex	F, M
age group	young, old
preceding segment	voiced stop, /w/, other
word frequency	subtlex
run	1st reading, 2nd reading
following place	alveolar, bilabial, dental, postalveolar, velar
following manner	obstruent, sonorant, affricate
following voice	voiced, voiceless
duration	continuous

model. Table 8 provides the factors which were coded for in the study: *county*, *sex*, *age group* and *reading* were coded as language-external factors, while *vowel*, *preceding segment*, *word frequency*, *following place*, *following manner*, *following voicing* and *duration* were coded as linguistic factors. These factors are broadly based on findings by Britain (2015) and Turton & Baranowski (2020). Word frequency is operationalised as a centred Zipf-scaled frequency from the SUBTLEX-UK corpus (van Heuven *et al.* 2014). First and second readings were coded for in order to detect if significant differences between the two readings occurred which could indicate that the speakers adjust their speech because they realised which sounds we were investigating. In none of the models was this factor significant, which means that the speakers did not change/adjust their pronunciation for FOOT and STRUT. Turton & Baranowski (2020) only conduct statistical modelling for F1 as they state that only height is relevant for the FOOT–STRUT split. As was shown above, F2 in FOOT sees the most dramatic changes, while F1 and F2 in STRUT are comparatively stable in apparent time. Hence, we fit a series of models for both F1 and F2 in order to investigate this complex set of changes with STRUT as intercept for F1 and FOOT as intercept for F2.

Appendices 2 and 3 provide the mixed-effects models including interactions for F1 and F2 for the overall sample.

6.1 Results for F1

Breaking down the sample into the different county samples, tables 9–14 provide the final mixed-effects models for Derbyshire, Nottinghamshire and Leicestershire. We investigate F1 variation for STRUT and F2 for FOOT. The results for F1 are discussed first. Linguistic factors which are significant in all three counties are *preceding segment* and *duration*. In addition, *vowel class* is significant, i.e. F1 is significantly different in FOOT and STRUT in each of the three counties. Turton & Baranowski (2020: 21f.) similarly find this

Table 9. *Mixed-effects linear regression on Derbyshire F1 values of the overall sample by vowel, age group, sex, preceding segment, duration and the interaction between vowel and age group and vowel, age group and sex. Random intercepts for speaker and word are included. N = 949*

Fixed effects	Estimate	Std error	df	T value	P value	
(Intercept)	634.3692	16.7335	324.4488	37.910	< 2e–16	***
Vowel						
STRUT (baseline)						
FOOT	−41.0036	10.9371	46.4700	−3.749	0.000491	***
Age group						
Old (baseline)						
Young	−20.9776	9.3711	45.5506	−2.239	0.030116	*
Sex						
F (baseline)						
M	14.1159	9.5983	49.3870	1.471	0.147724	
Preceding segment						
Other (baseline)						
Voiced stop	−0.6726	11.8109	27.1296	−0.057	0.955004	
/w/	−46.6851	14.9984	26.5515	−3.113	0.004403	**
Duration	27.0223	11.6795	908.0821	2.314	0.020909	*
FOOT: male	0.8782	9.5025	915.1672	915.1672	0.926387	
FOOT: young	36.5334	9.2262	905.1885	3.960	8.09e–05	***
Male: young	14.2544	13.5735	49.6556	49.6556	0.298726	
FOOT: young: male	−27.1719	13.3970	909.8703	−2.028	0.042829	*
Random intercepts	Variance	Std dev.				
Word	425.95	20.639				
N = 29						
Speaker	90.96	9.537				
N = 20						

statistical distinction in Manchester, even though the speakers who were included in the sample did not make a distinction between the two vowel categories in a minimal pair test.

Duration is significant in all three counties with longer vowels having higher F1 values. This is also in line with Turton & Baranowski's (2020: 23) finding for Manchester English. They argue that the jaw has more time to open to produce the vowel, which seems to be the case here as well.

In all three counties preceding /w/ was a significant factor, while voiced stops and /ʃ/ are not found to be significant preceding environments in this study. Turton & Baranowski (2020: 22) argue that some form of lip-rounding is part of the production which matches the realisation of STRUT as rounded /ʊ/ vowel in Manchester English. In the East Midlands data set all tokens which contain preceding /w/ belong to the FOOT vowel. The limited number of lexical items in

Table 10. *Mixed-effects linear regression on Derbyshire F2 values of the overall sample by vowel, age group, sex, following place, following voicing, duration and the interaction between vowel and age group and vowel and sex. Random intercepts for speaker and word are included. N = 949*

Fixed effects	Estimate	Std error	df	T value	P value	
Intercept	1,037.98	56.14	145.00	18.490	< 2e–16	***
Vowel						
FOOT (baseline)						
STRUT	96.50	52.24	36.98	1.847	0.07273	
Age group						
Old (baseline)						
Young	12.47	34.38	22.85	0.363	0.72010	
Sex						
F (baseline)						
M	29.03	34.36	22.79	0.845	0.40686	
Following place						
Alveolar (baseline)						
Bilabial	−183.15	60.91	29.11	−3.007	0.00539	**
Dental	38.15	103.02	27.11	0.370	0.71405	
Postalveolar	92.81	75.64	29.04	1.227	0.22970	
Velar	−53.83	65.03	30.25	−0.828	0.41429	
Following voice						
Voiced (baseline)						
Voiceless	−145.80	56.77	30.54	−2.568	0.01534	*
Duration	−232.21	31.24	945.39	−7.433	2.38e–13	***
STRUT: young	−104.61	24.11	904.82	−4.338	1.60e–05	***
STRUT: male	−62.39	24.90	910.26	−2.506	0.01238	*
Male: young	18.81	48.65	22.90	0.387	0.70250	
STRUT: male: young	46.84	35.05	907.10	1.336	0.18173	
Random intercepts	Variance	Std dev.				
Word	8,333	91.28				
N = 29						
Speaker	2,364	48.62				
N = 20						

this study due to the collection method might have an influence on the limited explanatory power of this linguistic constraint.

Age group as an external factor is significant for Derbyshire and Nottinghamshire at the level of p < 0.05, which is an indicator that we observe a change in progress but it is not significant in Leicestershire, i.e. STRUT F1 in Leicestershire does not differ significantly between the age groups, as also shown in figures 11 and 12. In none of the three counties is sex statistically significant for variation in F1. However, the factor surfaces in interactions with age and vowel in all three counties, suggesting that (young) men

Table 11. *Mixed-effects linear regression on Nottinghamshire F1 values of the overall sample by vowel, age group, sex, preceding segment, duration and the interaction between vowel and age group and vowel, sex and age group. Random intercepts for speaker and word are included.*
N = 917

Fixed effects	Estimate	Std error	df	T value	P value	
Intercept	673.135	18.443	274.017	36.499	< 2e–16	***
Vowel						
STRUT (baseline)						
FOOT	−65.950	10.465	64.506	−6.302	2.98e–08	***
Age group						
Old (baseline)						
Young	−25.991	12.614	34.585	−2.060	0.04694	*
Sex						
F (baseline)						
M	−10.255	12.540	33.785	−0.818	0.41920	
Preceding segment						
Other (baseline)						
Voiced stop	8.038	10.208	20.084	0.787	0.44023	
/w/	−45.294	12.469	26.739	−3.633	0.00117	**
Duration	27.566	12.295	759.092	2.242	0.02524	*
FOOT: male			880.229			
FOOT: young	56.703	10.757	879.196	5.271	1.71e–07	***
Male: young	21.710	17.745	33.886	1.223	0.22958	
FOOT: male: young	−47.146	14.824	880.457	−3.180	0.00152	**
Random intercepts	Variance	Std dev.				
Word	261.12	16.17				
N = 28						
Speaker	227.8	15.09				
N = 20						

are retaining the distinction between FOOT and STRUT on the height level for longer than women.

6.2   Results for F2

The statistical models for F2 confirm the observations in the data analysis section. F2 is significantly higher for younger speakers in Nottinghamshire and Leicestershire than for older speakers, i.e. younger speakers produce their FOOT vowel further front than older speakers. This finding indicates a change in progress in Nottinghamshire and Leicestershire, while age is not significant in Derbyshire. Similarities between the counties are that *sex* is not a predictor for the variation in F2 and duration is again significant. If FOOT is followed by a bilabial consonant, the vowel is less fronted.

Table 12. *Mixed-effects linear regression on Nottinghamshire F2 values of the overall sample by vowel, age group, sex, following place, following voicing duration and the interaction between vowel and age group and age group and sex. Random intercepts for speaker and word are included. N = 917*

Fixed effects	Estimate	Std error	df	T value	P value	
Intercept	1,007.529	59.098	133.725	17.048	< 2e–16	***
Vowel						
FOOT (baseline)						
STRUT	54.285	53.570	33.329	1.013	0.31820	
Age group						
Old (baseline)						
Young	229.720	43.869	22.793	5.236	2.67e–05	***
Sex						
F (baseline)						
M	27.563	43.489	22.024	0.634	0.53274	
Following place						
Alveolar (baseline)						
Bilabial	−125.611	60.571	26.879	−2.074	0.04781	*
Dental	7.481	99.723	24.879	0.075	0.94080	
Postalveolar	110.066	77.106	25.755	1.427	0.16546	
Velar	3.932	68.348	25.235	0.058	0.95458	
Voice						
Voiced (baseline)						
Voiceless	−196.163	59.166	25.915	−3.315	0.00271	**
Duration	−263.501	32.230	906.038	−8.176	9.88e–16	***
STRUT: young	−156.185	27.232	875.579	−5.735	1.34e–08	***
STRUT: male	−36.421	26.430	875.616	−1.378	0.16856	
Young: male	−138.457	61.597	22.154	−2.248	0.03487	*
STRUT: young: male	37.894	37.549	875.813	1.009	0.31316	
Random intercepts	Variance	Std dev.				
Word	7,640	87.41				
N = 28						
Speaker	4,043	63.58				
N = 20						

Similarly, this is the case if the following segment is voiceless (segments covered in the text passage: /t p k ʃ/). Torgersen ([2002](#)) observes that the following voiceless consonants /k/ and /t/ favour FOOT-fronting in the south-east of England but comes to no conclusion as to why this would be the case. The interactions reveal that young men retain a more retracted FOOT vowel than women, i.e. young women are driving the change towards FOOT-fronting. Again, Torgersen ([2002](#)) finds a similar pattern with girls driving the change towards FOOT-fronting in the south-east.

The presentation of results shows that we are dealing with a complex system of changes in FOOT and STRUT in the East Midlands. The findings are discussed in the following section.

Table 13. *Mixed-effects linear regression on Leicestershire F1 values of the overall sample by vowel, age group, sex, preceding segment, duration and the interaction between vowel and sex, vowel and age group and vowel, sex and age group. Random intercepts for speaker and word are included. N = 965*

Fixed effects	Estimate	Std error	df	T value	P value	
(Intercept)	667.930	19.340	192.713	34.536	< 2e–16	***
Vowel						
STRUT (baseline)						
FOOT	−59.458	10.939	49.754	−5.435	1.65e–06	***
Sex						
F (baseline)						
M	−11.399	15.091	27.386	−0.755	0.456470	
Age group						
Old (baseline)						
Young	−7.628	15.236	28.435	−0.501	0.620460	
Preceding segment						
Other						
Voiced stop	5.680	11.726	23.196	0.484	0.632660	
/w/	−54.288	14.373	24.515	−3.777	0.000899	***
Duration	37.223	12.257	820.489	3.037	0.002466	**
FOOT: male	22.832	9.554	925.811	2.390	0.017052	*
FOOT: young	45.569	9.842	925.261	4.630	4.18e–06	***
Male: young	1.878	21.370	27.523	0.088	0.930624	
FOOT: male: young	−33.878	13.611	925.200	−2.489	0.012985	*
Random intercepts	Variance	Std dev.				
Word	384.0	19.60				
N = 28						
Speaker	430.4	20.75				
N = 20						

7   Discussion

The overall finding is that no complete overlap between FOOT and STRUT exists in any of the counties under investigation in the East Midlands,[3] but we also find that FOOT and STRUT do not pattern homogeneously across the East Midlands. The results in tables 9–14 show that F1 and F2 in Leicestershire and Nottinghamshire are different from those acoustic dimensions in Derbyshire. What we mainly observe is a change in FOOT F2 in Leicestershire and Nottinghamshire and STRUT F2 in Derbyshire, but these separate changes both result in an increased overlap between FOOT and STRUT in the younger speaker group in each of the three counties under investigation. Hence while we see

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[3] However, the lack of complete overlap does not mean that every speaker has a phonemic split, as discussed in point 4 below.

Table 14. *Mixed-effects linear regression on Leicestershire F2 values of the overall sample by vowel, age group, sex, following place, following voicing, duration and the interaction between vowel and age group, vowel and sex and vowel, sex and age group. Random intercepts for speaker and word are included. N = 965*

Fixed effects	Estimate	Std error	df	T value	P value	
Intercept	1,183.91	60.55	101.58	19.552	< 2e–16	***
Vowel						
FOOT (baseline)						
STRUT	126.55	60.79	30.30	2.082	0.04591	*
Age group						
Old (baseline)						
Young	140.31	41.93	21.61	3.346	0.00297	**
Sex						
F (baseline)						
M	−6.91	41.81	21.37	−0.165	0.87029	
Following place						
Alveolar (baseline)						
Bilabial	−141.30	67.09	28.09	−2.106	0.04424	*
Dental	−10.48	114.89	26.27	−0.091	0.92802	
Postalveolar	114.50	88.18	26.68	1.299	0.20521	
Velar	−16.56	77.20	27.00	−0.215	0.83175	
Voice						
Voiced (baseline)						
Voiceless	−186.59	68.04	26.60	−2.742	0.01077	*
Duration	−148.53	30.10	954.26	−4.935	9.46e–07	***
STRUT: young	−160.38	23.44	922.58	−6.842	1.42e–11	***
STRUT: male	−128.03	22.76	922.96	−5.624	2.47e–08	***
Male: young	−10.92	59.18	21.44	−0.184	0.85539	
STRUT: male: young	104.72	32.41	922.26	3.231	0.00128	**
Random intercepts	Variance	Std dev.				
Word	10,389	101.93				
N = 28						
Speaker	3,865	62.17				
N = 20						

some split tendencies on the phonetic level for the older speaker group, in particular in Leicestershire and Nottinghamshire, the younger groups increase the phonetic overlap.

Based on the present study a number of findings regarding the status of the FOOT–STRUT split in the East Midlands need to be discussed:

1. In all three counties, both vowels, on average, remain further back than where we would consider the midpoint of the vowel space to be, i.e. a schwa-like realisation. The vowel realisation can be described as phonetically intermediate between [ə] and [ʊ]. Chambers & Trudgill (1998) and Trudgill (1986) proposed that speakers settle on a

phonetic compromise between the [ʊ] and [ʌ] production for STRUT, i.e. the fudged variant. [ɤ] might indeed be the phonetic form of STRUT; however, speakers in the East Midlands are now also producing FOOT in this area. Torgersen (2002 based on Cruttenden 1994) reports less lip rounding for FOOT for some RP speakers; however, we did not include F3 measurements to investigate differences in the use of lip rounding. In the future, an additional analysis of lip rounding in both vowels in the East Midlands is needed to show how complete the overlap in oral gestures between the two vowels really is.

2. In all three counties the overlap between FOOT and STRUT *increases* in apparent time, i.e. a change towards a phonetic split between FOOT and STRUT is not observable across the two age groups under investigation in this study. This finding is contrary to our expectation that we would observe an increased phonetic distance between FOOT and STRUT in the three counties based on the claims by Trudgill (1986) and the findings by Leemann *et al.* (2018). However, even though Bhattacharyya's Affinity is an improved measure for investigating vowel overlap, these measurements only tell half of the story. The increased overlap between FOOT and STRUT mainly results from FOOT-fronting and slight lowering. The changes in FOOT and the fairly stable STRUT vowel in Leicestershire and Nottinghamshire are quite surprising as this scenario of change has not been discussed before.

The results in this article suggest that FOOT and STRUT are fronting at different rates in Leicestershire and Nottinghamshire (figures 8, 11 and 12). Since FOOT started in a backer position in vowel space than STRUT, yet ended in a comparably similar position with respect to frontness, it could be argued that FOOT-fronting is advancing faster than STRUT-fronting. Furthermore, STRUT seems to be almost stable across apparent time in those two counties. This is particularly the case for the Nottinghamshire speakers in our dataset. Indeed, for these speakers, very little overall movement of STRUT was observable. Again, this is a surprising finding as we had expected for STRUT to move in the vowel space, not FOOT.

3. The realisation of FOOT and STRUT in the East Midlands is somewhat variable, with the majority of speakers showing very high rates of overlap, but a few speakers have less overlap in their vowel realisation. However, it comes as a surprise that even with the observed interspeaker variation, the change towards two phonetically completely separated vowels is very limited. Given that the SED already described quite some variation for Leicestershire in the middle of the twentieth century, it seems as if this variation towards a (phonetic) split has not expanded in this county. The somewhat lower overlap measurements for older women in Leicestershire might be a reminiscence of a movement towards the phonetic split.

Another observation is that the overlap between FOOT and STRUT is higher in Leicestershire than in Nottinghamshire though the overlap measurement differences are not statistically significant. This is surprising because Nottinghamshire is located further north than Leicestershire and the SED, MMB and *BBC Voices* results (shown in table 1) suggest that there is less variation in Nottinghamshire than in Leicestershire. We do not want to make any broad claims about this finding at the moment but leave it for further investigation. Only a more community-based study will provide information about this result.

4. Speakers of both age groups in Derbyshire show more overlap between FOOT and STRUT than in Leicestershire and Nottinghamshire and they have no significant FOOT-fronting, i.e. speakers in Derbyshire make more conservative choices than the speakers in Leicestershire and Nottinghamshire. The data also show that the overlap between FOOT and STRUT for the individuals in the older speaker group was highest in Derbyshire compared to the older speakers in the other two counties. This information in addition to the findings in the SED led to the assumption that previously FOOT and STRUT were more advanced in undergoing change towards a split in Nottinghamshire and Leicestershire but less so in Derbyshire.

While STRUT is fairly stable or rather fronting slightly in the Leicestershire and Nottinghamshire sample, the vowel is retracting in Derbyshire. Hence, the increase of overlap on the F2 dimension is due to the fronting of FOOT in Leicestershire and Nottinghamshire but due to the retraction of STRUT in Derbyshire. Therefore, diverging trends in the realisation of FOOT and STRUT are observable within the East Midlands. Speakers in Leicestershire and Nottinghamshire seem to participate in a change which has been described for the south-east of England, namely FOOT-fronting, e.g. by Torgersen (2002), Torgersen & Kerswill (2004) and Fabricius (2007), while Derbyshire speakers seem to pattern more with northern English speakers and even more so in the group of younger speakers.

This finding raises the question of homogeneity in the realisation of FOOT and STRUT but also the phonemic status of the two vowels in the East Midlands. Jansen (2019) makes the observation that FOOT-fronting is only apparent in varieties which have the FOOT–STRUT split. Therefore, FOOT-fronting in Leicestershire and Nottinghamshire could be an indicator that FOOT and STRUT might have developed a separate phonemic status before the innovative increase in phonetic overlap between the vowels. However, this is not the case in Derbyshire as yet. Therefore, we might indeed see a slow northward movement of the FOOT–STRUT split, as predicted by Trudgill (1986), but it manifests phonetically as the fronting of FOOT rather than the realisation of FOOT and STRUT as completely separate phonetic entities.

Admittedly, this study is a broad brush across the East Midlands when it comes to FOOT–STRUT variation. However, the multilocality approach taken here provides initial insights into 'a sound change as it moves through the linguistic system' (Horvath & Horvath 2001: 37) of the East Midlands. Dimensions such as urban–rural, social class and ethnicity have not been taken into account here but pose important factors – as Drummond (2012) and Turton & Baranowski (2020) have shown – in understanding variation and change of FOOT–STRUT changes in the East Midlands based on community studies, which we plan to conduct in the future. In addition, this study is based on read data, which might have an influence on the use of vowel variation. Future research needs to incorporate stylistic variation in order to avoid self-conscious changes in the use of STRUT, as reported by Docherty & Foulkes (1999) for Derby, and to achieve a holistic view on the variation of FOOT and STRUT. The present study should therefore be treated as providing initial insights into the status of FOOT–STRUT variation in this region.

8 Conclusion

This article set out to examine the FOOT–STRUT split in the East Midlands region. We know from the small amount of previous research that the East Midlands is a linguistically interesting region as it falls between the geographical and linguistic north and south. Using earlier dialectological sources allowed us to establish the relationship between FOOT and STRUT in three counties of the East Midlands in the first half of the twentieth century. The results showed us that although for most speakers there was little variation between STRUT and FOOT, there were some indications in Leicestershire (the most southerly county) that the southern [ʌ] form was infrequently found in STRUT words, as well as a few intermediate variants.

 We have argued that at the end of the second decade of the twenty-first century the emerging FOOT-fronting in Leicestershire and Nottinghamshire seems to indicate a northward movement of the phonemic split, while phonetically FOOT and STRUT become more similar. In Derbyshire, on the other hand, not FOOT fronting but STRUT retraction is observed, which leads to the assumption that speakers in this county still retain the lack of the split and cluster with northern English speakers.

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Appendix 1: Reading passage

Underlined words = STRUT words; bold words = FOOT words.

Tina and Duncan were really happy. Last Sunday they had visited Newcastle with their father for the day. It was an open day at the university and they were going to have a **look** at what it **would** be like to be students at the school of humanities in the far north of the country. After an early start and enjoying the facade of the building they visited student accommodation and the adjacent **woods**. The **cooking** facilities were **good** but the **butcher** around the corner **looked** even better. The students asked them to stay for a dance party. Both were very excited but tried to stay calm.

After the visit the staff asked the two southerners if they **could** imagine moving as far as Newcastle and they happily said yes. This morning they were talking about a funny story in the newspaper. A pub called the Grumpy Duke of Gloucester was in the news for winning the prize for best tuna sandwiches and the pub landlord didn't even like fish. Both were laughing about this story.

As Tina **stood** in the kitchen in her pyjamas, humming a tune and making a cup of tea, Duncan sat on a **cushion** enjoying the calm reading through a part of the newspaper and tearing out the special offer to get half price beef stew and mushy peas at his favourite canteen. He **pushed** the **wooden** stool away from the table to grab the **book** from the basket.

A drama, he was supposed to read for the **book** club tonight though he **would** have preferred to go to a **football** match. The **book** was about famous chefs who can't really **cook**.

Appendix 2: Mixed-effects model output of F1 in all three counties including interactions

```
Linear mixed model fit by maximum likelihood . t-tests use Satterthwaite's method ['lmerModLmerTest']
Formula: norm_F1 ~ F2vowel * County * Sex * Age + (1 | Name) + (1 | word) +       preseg + durlog
   Data: FOOT_STRUT

    AIC      BIC   logLik deviance df.resid
 30637.0  30815.5 -15288.5  30577.0     2801

Scaled residuals:
    Min      1Q  Median      3Q     Max
-4.1969 -0.6123 -0.0181  0.5682  7.1120

Random effects:
 Groups   Name        Variance Std.Dev.
 Name     (Intercept) 247.5    15.73
 word     (Intercept) 345.5    18.59
 Residual             2708.0   52.04
Number of obs: 2831, groups:  Name, 60; word, 32

Fixed effects:
                                 Estimate Std. Error       df t value Pr(>|t|)
(Intercept)                       632.908     13.506  266.085  46.862  < 2e-16 ***
F2vowelFOOT                       -37.585     10.298   67.565  -3.650 0.000512 ***
CountyL                            26.788     12.472   95.482   2.148 0.034253 *
CountyN                            43.957     12.535   97.264   3.507 0.000688 ***
SexM                               12.555     12.617   99.669   0.995 0.322119
AgeY                              -22.269     12.412   93.696  -1.794 0.076002 .
presegvoicedstop                    2.203     10.194   27.888   0.216 0.830453
presegw                           -47.781     12.583   26.302  -3.797 0.000780 ***
durlog                             29.445      7.143 2689.103   4.122 3.86e-05 ***
F2vowelFOOT:CountyL               -23.789      9.642 2750.084  -2.467 0.013679 *
F2vowelFOOT:CountyN               -31.023      9.841 2755.085  -3.152 0.001637 **
F2vowelFOOT:SexM                    2.394      9.890 2761.937   0.242 0.808754
CountyL:SexM                      -23.830     17.764   98.039  -1.342 0.182854
CountyN:SexM                      -23.673     17.848   99.827  -1.326 0.187741
F2vowelFOOT:AgeY                   37.849      9.599 2745.603   3.943 8.24e-05 ***
CountyL:AgeY                       15.294     17.709   96.954   0.864 0.389924
CountyN:AgeY                       -3.203     17.749   97.816  -0.180 0.857159
SexM:AgeY                          17.258     17.839   99.695   0.967 0.335654
F2vowelFOOT:CountyL:SexM           20.619     13.849 2758.896   1.489 0.136631
F2vowelFOOT:CountyN:SexM            6.782     14.043 2759.556   0.483 0.629184
F2vowelFOOT:CountyL:AgeY            7.016     13.839 2751.212   0.507 0.612220
F2vowelFOOT:CountyN:AgeY           18.893     14.070 2751.844   1.343 0.179453
F2vowelFOOT:SexM:AgeY             -29.912     13.964 2755.062  -2.142 0.032275 *
CountyL:SexM:AgeY                 -15.932     25.154   98.572  -0.633 0.527962
CountyN:SexM:AgeY                   4.745     25.252  100.105   0.188 0.851326
F2vowelFOOT:CountyL:SexM:AgeY      -3.863     19.656 2755.640  -0.197 0.844220
F2vowelFOOT:CountyN:SexM:AgeY     -17.986     19.900 2755.311  -0.904 0.366173
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Appendix 3: Mixed-effects model output of F2 in all three counties including interactions

```
Linear mixed model fit by maximum likelihood . t-tests use Satterthwaite's method ['lmerModLmerTest']
Formula: norm_F2 ~ vowel * County * Age * Sex + (1 | Name) + (1 | word) +
    followingplace + followingvoice + durlog
  Data: FOOT_STRUT

    AIC      BIC   logLik deviance df.resid
 35935.4  36131.7 -17934.7  35869.4     2798

Scaled residuals:
    Min      1Q  Median      3Q     Max
-4.9797 -0.5840 -0.0419  0.5294  7.1616

Random effects:
 Groups   Name        Variance Std.Dev.
 Name     (Intercept)  3254     57.04
 word     (Intercept)  8136     90.20
 Residual             17121    130.85
Number of obs: 2831, groups: Name, 60; word, 32

Fixed effects:
                                  Estimate Std. Error       df t value Pr(>|t|)
(Intercept)                       1063.781     47.467  123.676  22.411  < 2e-16 ***
vowelSTRUT                          82.363     50.858   40.387   1.619 0.113129
CountyL                             31.874     39.142   66.213   0.814 0.418390
CountyN                              4.995     39.317   67.406   0.127 0.899275
AgeY                                14.573     39.219   66.735   0.372 0.711385
SexM                                29.769     39.216   66.722   0.759 0.450473
followingplacebilabial            -147.845     57.818   31.027  -2.557 0.015666 *
followingplacedental                14.478    100.035   28.323   0.145 0.885949
followingplacepostal               112.019     73.275   30.116   1.529 0.136767
followingplacevelar                -11.767     62.489   32.633  -0.188 0.851798
followingvoicevoiceless           -176.518     54.632   31.976  -3.231 0.002856 **
durlog                            -209.926     18.200 2808.678 -11.534  < 2e-16 ***
vowelSTRUT:CountyL                  52.125     24.262 2749.843   2.148 0.031766 *
vowelSTRUT:CountyN                  -6.402     24.765 2752.115  -0.259 0.796028
vowelSTRUT:AgeY                   -104.287     24.142 2745.482  -4.320 1.62e-05 ***
CountyL:AgeY                       121.609     55.517   66.987   2.191 0.031972 *
CountyN:AgeY                       214.952     55.821   68.452   3.851 0.000262 ***
vowelSTRUT:SexM                    -63.540     24.903 2757.661  -2.552 0.010777 *
CountyL:SexM                       -36.486     55.426   66.554  -0.658 0.512624
CountyN:SexM                        -4.451     55.560   67.202  -0.080 0.936381
AgeY:SexM                           16.068     55.492   66.870   0.290 0.773050
vowelSTRUT:CountyL:AgeY            -54.286     34.817 2749.670  -1.559 0.119063
vowelSTRUT:CountyN:AgeY            -56.349     35.399 2749.339  -1.592 0.111538
vowelSTRUT:CountyL:SexM            -63.490     34.865 2755.459  -1.821 0.068709 .
vowelSTRUT:CountyN:SexM             23.775     35.351 2755.263   0.673 0.501295
vowelSTRUT:AgeY:SexM                51.468     35.141 2752.407   1.465 0.143142
CountyL:AgeY:SexM                  -22.595     78.439   66.738  -0.288 0.774198
CountyN:AgeY:SexM                 -153.533     78.660   67.486  -1.952 0.055105 .
vowelSTRUT:CountyL:AgeY:SexM        44.195     49.464 2752.388   0.893 0.371685
vowelSTRUT:CountyN:AgeY:SexM        -2.381     50.078 2751.737  -0.048 0.962080
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```