Articulation at the end stage of sound change:

Derhoticisation across east Lancashire[1]

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Competing interests

The authors declare none.

Abstract

This paper presents a socioarticulatory analysis of sound change in English across communities. In particular, we focus on loss of coda rhoticity, a known locus of complex perceptual, acoustic, and articulatory relations which occupies an important position in the history of English dialectology. Our analysis compares two geographically close communities at different stages of sound change in order to assess the articulatory mechanisms responsible for the progression of derhoticisation. We compare recordings from participants in Blackburn and Burnley, east Lancashire. Analysis includes auditory coding for rhoticity, dynamic acoustic comparison of dialects, and Multivariate Functional Principal Component Analysis of tongue shapes across the syllable in rhoticity minimal pairs. Forty-one participants were included in the auditory and acoustic analyses and thirty-five in the articulatory analysis. Results show greater retention of coda rhoticity in Blackburn compared to Burnley, and that this residual east Lancashire rhoticity is usually produced with tip-up tongue gestures. In our cross-community comparison, Burnley speakers time tongue fronting later and reduce the magnitude and timing of the tongue root gestures for rhotic tokens. We conclude that loss of tongue root gestures is the signature of the final stage of this significant English sound change.

Keywords

Rhoticity, Lancashire, Ultrasound, Phonetics, Articulation

1 INTRODUCTION

In this study, we investigate articulatory variation during the progression of a sound change which is close to completion: loss of coda rhoticity in English spoken in England. English derhoticisation is a complex sound change involving multiple articulatory dimensions and complex perceptual-acoustic-articulatory relationships (Stuart-Smith, Lawson & Scobbie 2014). It has also been widely reported that rhotics can involve multiple different articulations for similar acoustic outputs (Mielke, Baker & Archangeli 2016). Variation in articulation has long been considered one of the primary factors in sound change *actuation*. Language-internal sound changes can originate in patterns of gestural undershoot or overlap, resulting in a pool of new variants which listeners might recategorise (Ohala 1989), while coarticulation can lead to a gradual re-weighting of perceptual cues for contrast (Beddor et al. 2018). Our study, however, investigates two closely related dialects where derhoticisation is *near-complete*. Our aim is to understand the structure and extent of variation in articulation at the very end stage of sound change. In doing so, we assess the articulatory mechanisms behind ongoing derhoticisation and how these relate to acoustic realisations, auditory-perceptual correlates, and thus the spread of change across communities.

Our analysis includes auditory and acoustic analysis of 41 residents of east Lancashire in the United Kingdom (18 from Blackburn and 23 from Burnley), and analysis of ultrasound recordings from 35 participants (13 from Blackburn and 22 from Burnley). Data were collected in marketplaces during community outreach events (Nance et al. 2024). Our data collection and study design were planned to facilitate obtaining articulatory recordings in a community setting from participants who might not usually travel to our lab (see Section 3.1). The first analysis addresses the distribution of rhoticity across east Lancashire including auditory perception, acoustics (dynamic F3–F2 across syllable codas), and assessment for rhoticity in tongue shape at 80% of syllable coda duration in minimal pairs. Secondly, we consider the realisation of derhoticising articulations across vowel contexts. Previous work indicates that either gestural reduction or gestural timing can explain the majority of sound changes (Cunha et al. 2024). In order to apply this framework to derhoticisation in Lancashire, we use Functional Principal Component Analysis to decompose the tongue shapes into quantitative and comparable vectors across the vowel(+rhoticity) interval (Coretta & Sakr 2026). Our analysis investigates the possibility of community-level differences in realisation of rhoticity minimal pairs. In doing so, we assess community-level differences in gestural timing and magnitude in order to track the articulation of a changing sound as it diffuses.

2 BACKGROUND

2.1 The role of articulation in sound change

Approaches to sound change have often theorised the actuation and spread of change as separate processes (Ohala 1981; Weinreich, Labov & Herzog 1968). In this model, there is some consensus that variation from articulation provides the ‘raw material’ for actuation of many forms of change (Beddor 2023:4). Ohala (1981) describes how various coarticulatory factors lead to variation in the speech signal, which then might get reinterpreted in a process of change. For example, Middle Indo-Aryan breathy voiced consonants produced differences in adjacent vowel pitch, which was then reinterpreted as a tonal contrast in Punjabi (p. 191). Similarly, articulatory processes involved in speech production can lead to change; for example, Spanish intervocalic stops become fricatives due to the faster speech needed for voicing, and subsequent target undershoot (Ohala 1989:179). In the Articulatory Phonology (AP) framework, target undershoot (i.e. gestural reduction) and gestural phasing generate variation that can form the basis for sound change actuation (Browman & Goldstein 1991; Iskarous & Pouplier 2022). Specifically, AP predicts that apparently qualitative alternations can be a consequence of quantitative variation in the degree of gestural overlap or the relative timing of two gestures, for example in the change from pre- to post-aspiration of stops in the Andalusian Spanish change from /s/+voiceless stop to pre-aspiration (Cronenberg et al. 2020; Parrell 2012; Ruch & Harrington 2014).

Our study examines articulatory variation as a sound change continues to spread in English dialects. We wish to examine whether the changes proposed in actuation (gestural reduction and gestural timing) are present in communities at different stages of a change. And if so, how these relate to the acoustic output produced and its auditory-perceptual realisation. Our inspiration stems from recent articulatory work in derhoticising communities in Scotland and England (Lawson & Stuart-Smith 2021; Lawson, Scobbie & Stuart-Smith 2011; Stuart-Smith, Lawson & Scobbie 2014; Turton & Lennon Under review). As the basis of spoken communication, we assume articulatory variation must play a role in the transmission of sound change (Carignan 2014). However, rhoticity provides an intriguing window into this process due to the complex and non-linear relationships between acoustics, articulation and perception. We now discuss these relationships in more detail, and how derhoticisation in Anglo British English relates the goals of our study.

2.2 Derhoticisation in British English

Our analysis considers loss of rhoticity in English dialects spoken in England. Coda rhoticity, the presence or absence of /r/ in words such as ‘far’ or ‘farm’, has been described as the ‘most fundamental division in English dialects’ (Lawson & Stuart-Smith 2021:1). Varieties of English can typically be categorised as rhotic (e.g. most varieties of North American English, Irish English) or non-rhotic (e.g. English in the south-east of England, North Island New Zealand English). Presence or absence of coda rhoticity has long been studied as a sociolinguistic variable in communities where rhoticity is undergoing change or is subject to social stratification. Indeed, rhoticity became the emblematic variable in variationist sociolinguistics via Labov’s seminal department store study, which aimed to investigate class-based variation in rhoticity realisation (Labov 1966).

In the UK, coda rhoticity realisation is variable according to region, nation, and social factors such as class, ethnicity, and gender. A substantial body of work in Scotland has uncovered variation in audible rhoticity where strong rhoticity is associated with middle-class speech and weaker rhoticity with working-class Scottish English (Dickson & Hall-Lew 2017; Lawson, Scobbie & Stuart-Smith 2011; Lawson, Stuart-Smith & Scobbie 2018; Stuart-Smith, Lawson & Scobbie 2014). It is thought that this change in working-class speech is a very gradual variety-internal change, rather than a change resulting from contact with English English in most cases (Lawson & Stuart-Smith 2021). We return to the acoustics and articulation or Scottish English /r/ in Section 2.3.

In England, rhoticity loss is a long-term sound change which has been ongoing since at least the 1700s, or possibly with origins during the Middle English period form

1400 onwards (McMahon 2000; Wells 1982). Historically, this change has proceeded at different rates in different locations, and in differing linguistic contexts. For example, Gordon et al. (2004:320) demonstrate that almost all of England had some kind of rhoticity in the 1700s, but this was already being lost in some contexts for some speakers. McMahon (2000:234) suggests that the loss of rhoticity took place in (most of) England via three sound changes in the eighteenth century onwards:

1. Pre-/r/ breaking (schwa insertion) e.g. chair [tʃeːr] > [tʃeːər].
2. Pre-schwa laxing/shortening e.g. chair [tʃeːər] > [tʃɛər].
3. /r/-deletion pre-consonantally and pre-pausally e.g. chair [tʃɛər] > [tʃɛː].

In contemporary England, coda rhoticity is variably produced in the south-west (Blaxter et al. 2019; Piercy 2012), and east Lancashire. Due to Lancashire being the only contemporary part of northern England to retain rhoticity, this feature is a salient marker of Lancashire speech (Barras 2015:277) and ‘popularly supposed’ to be a distinguishing feature of the dialect (Wells 1982:367). In the nineteenth and early twentieth century, much of Lancashire and contemporary Greater Manchester was variably rhotic (Barras 2010; Dann, Ryan & Drummond 2022; Ryan, Dann & Drummond 2022; Nance & Mahamdi 2026). Today, however, east Lancashire has been described as an ‘island of rhoticity’ in comparison to surrounding non-rhotic areas (Britain 2009; Vivian 2000). Specifically, rhoticity is often realised in Blackburn and Rossendale, but is more variable in Burnley (Austin 2007; Vivian 2000; Turton & Lennon 2023). This reported variation across east Lancashire allows us to compare Blackburn and Burnley as two towns at different stages of sound change. In terms of social meaning, rhoticity is generally stigmatised in the majority of England as representing a rural stereotype (Foulkes & Docherty 2007:65). In Lancashire, rhoticity is associated with working class identity, traditional values and male speech (Dann, Ryan & Drummond 2022:12). Within contemporary rhotic communities in Lancashire, there is little evidence that rhoticity is stigmatised and speakers are not generally aware of these stereotypes until they move outside their community (Turton & Lennon 2023:17).

2.3 Acoustic-articulatory-perceptual relationships in derhoticisation

As rhoticity is realised by multiple articulators, its acoustic characteristics are complex and varied. In addition, it is challenging to separately segment a coda vowel from a rhoticised vowel or coda rhotic approximant (Plug & Ogden 2003). For this reason, much of the sociolinguistic literature discussed above has used auditory coding to classify variants as rhotic and or non-rhotic (Blaxter et al. 2019; Labov 1966; Piercy 2012; Villarreal et al. 2021). This method has the advantage of relating to what listeners encounter in the speech community, but perceptions of rhoticity have been shown to be variable between listeners and subject to experience (Lennon 2024; Stuart-Smith, Lawson & Scobbie 2014). For this reason, many studies have either triangulated with acoustic measures or relied on acoustics to assess variable rhoticity (Dann, Ryan & Drummond 2022; Turton & Lennon 2023). The most widely used acoustic correlate of rhoticity is lowered F3 (Harper, Goldstein & Narayanan 2020; Love & Walker 2012), though some work has suggested that F3–F2 is more appropriate for characterising rhoticity in Lancashire due to the perceptual importance of raised F2 for rhoticity in this dialect region (Heselwood 2009; Turton & Lennon 2023; Nance et al. 2023).

Substantial progress has been made in understanding the complexity of rhoticity through articulatory analysis. For example in England, Turton & Lennon (Under review) have shown that rhoticity gestures are reduced across subsequent generations in Blackburn. In terms of the tongue shape used for rhoticity, Delattre & Freeman (1968) characterised north American rhoticity into a series of different tongue configurations. Subsequent research has often categorised rhotic tongue shapes as either produced with the tongue tip raised, or bunched tongue shape (Lawson, Scobbie & Stuart-Smith 2011; Mielke, Baker & Archangeli 2016; Nance & Kirkham 2022). In eastern central Scotland, working-class derhoticising speakers produced residual coda rhoticity with tip-up tongue shapes, and middle-class speakers with audibly stronger rhoticity produced bunched tongue shapes (Lawson, Scobbie & Stuart-Smith 2011). These findings were repeated in a comparison of eastern and western central Scottish speakers, which showed articulatory stratification for social class across central Scotland (Lawson, Scobbie & Stuart-Smith 2014). In this case, articulatory variation correlated with auditory perceptions of rhoticity or derhoticisation. In other cases, there does not seem to be such a clear link. For example, Mielke (2015) demonstrates that speakers achieve a variety of audibly rhotic vowels with similar acoustic correlates using both tip-up and bunched tongue shapes. Nance & Kirkham (2022) also find both tip-up and bunched tongue shapes with no discernible acoustic differences. It is suggested in Zhou et al. (2008) that there are few or no differences between these tongue shapes in the first three formants, though the tongue shapes may results in differences in F4 and F5.

The existence of different rhotic articulatory configurations with little or no acoustic differentiation poses the theoretical question as to what kinds of targets speakers are aiming to produce, and what information listeners respond to. In the case of coda rhoticity variation, it seems likely that listeners perceive an acoustic target and use varying articulatory strategies to reproduce this (Nagamine 2024:20; Nance &

Kirkham 2022). In this study, we wish to examine the roles of gestural reduction and timing to investigate whether there is any link between ongoing derhoticisation, acoustic correlates, and articulation. We hypothesise that the general articulatory mechanisms identified in actuation of sound change (reduction in gestural magnitude, gestural retiming) will also be present in the end stage of sound change diffusion. We predict that communities with auditorily different levels of rhoticity will use different gestural magnitudes in the realisation of rhoticity contrasts and will time these gestures differently. Previous work on rhoticity has identified that specific tongue shapes might not correspond to differences in acoustic output. We predict that dialect-specific differences in auditory impression and acoustics of rhoticity will correspond to articulatory differences in tongue movements used for rhoticity at the level of each dialect, and individual-level differences in specific tongue shape.

2.4 Summary and research questions

We investigate community variation in two closely related dialects as a window into understanding the progression of sound change (Schuchardt 1885, cited in Cunha et al. 2024:3), with a view towards understanding the articulatory mechanisms behind ongoing sound change. In particular, articulatory studies of derhoticisation have rarely considered a *cross-community* comparison (Lawson, Scobbie & Stuart-Smith 2014), rather they most often focus on *within-community* social class variation (Lawson, Scobbie & Stuart-Smith 2011; Lawson, Stuart-Smith & Scobbie 2018), or *within-community* generational comparison (Turton & Lennon Under review). We consider dialect variation *across derhoticising communities,* adding to the small number of articulatory studies addressing this kind of comparison (Lawson, Scobbie & Stuart-

Smith 2014). In doing so, we explore the relationship between acoustics, articulation, and auditory perceptions of derhoticising variants in an attempt to uncover the role articulation plays at the end stage of sound change. Specifically, we address the following research questions:

1. How is rhoticity realised in two communities undergoing derhoticisation (auditory perception, acoustics, articulation)?
2. What are the articulatory mechanisms behind derhoticisation? Does this vary between communities with differing rhoticity rates?

3 METHODS

The code and data for our analysis are available at https://osf.io/d3wk7.

3.1 Communities and data collection

The data for this study were collected in two east Lancashire towns, Blackburn and Burnley, which are 16km/10 miles apart (see Figure 1). Blackburn is slightly larger, population 163,000, and Burnley has a population of 99,000 (Lancashire County Council 2025). Both towns grew substantially during the Industrial Revolution due to the Lancashire cotton industry, and the landscape and architecture today reflect this post-industrial legacy. Despite extensive migration during the nineteenth and early twentieth century, the Lancashire dialect seems to have mainly been retained in these communities since immigration was steady, and mostly from surrounding parts of Lancashire (Kerswill 2018). Post WWII, the towns experienced substantial immigration from south Asia, and the populations are ethnically diverse today. For example, in Blackburn the population is 36% British Asian/Asian and in Burnley this figure is 15%

(Office for National Statistics 2025). In a post-industrial 21st century context, east Lancashire is economically disadvantaged. In a metric combining deprivation in education, employment, health, housing, both towns are in the bottom 3% of most deprived communities in England and Wales (Lancashire County Council 2025). Despite the relatively short distance between Blackburn and Burnley, local discourse and rivalries mean they are ideologically as well as geographically separate. For example, there is a fierce footballing rivalry between the towns which has endured since the origins of professional football in Britain (Lewis 1993; Hunter 2009). Linguistically, one of the inspirations for this study was during our first data collection in Blackburn, a large number of participants told us how distinct their accent was in comparison to neighbouring east Lancashire towns, especially Burnley. For these social and linguistic perceptual dialectology reasons, we analyse Blackburn and Burnley as separate communities.

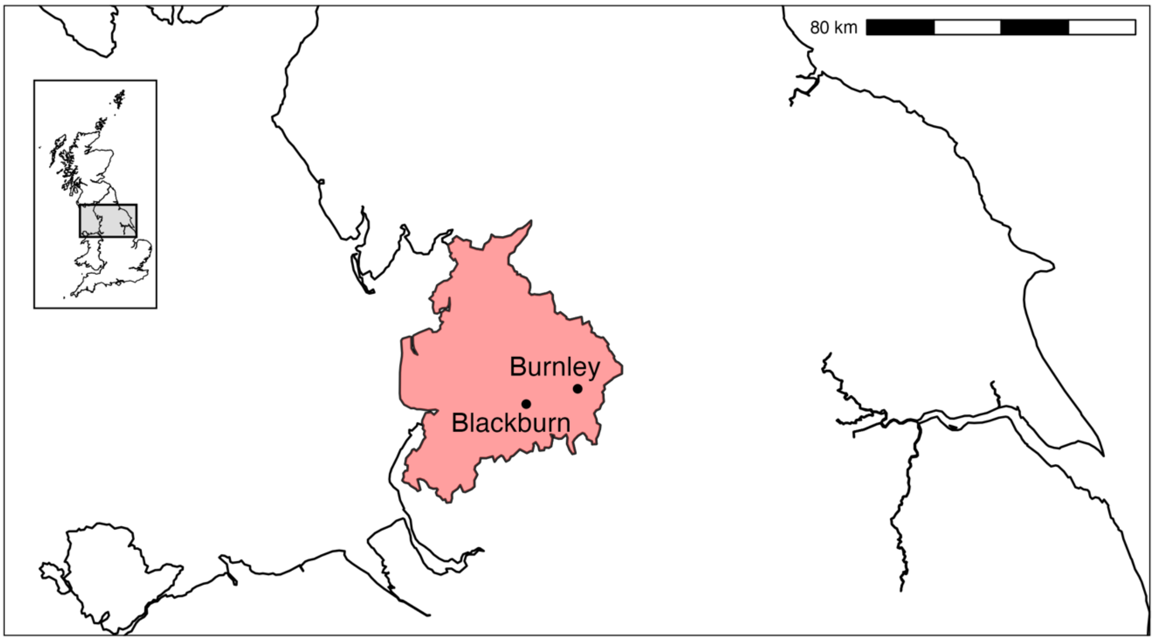

Figure 1: A map showing the locations of Blackburn and Burnley within the north-west of England. Red shading shows the contemporary ceremonial county of Lancashire.

Data were collected in Blackburn and Burnley markets as part of outreach events (Nance et al. 2024). Our lab team worked on a market stall in each location for the day and recorded interested members of the public. In terms of the quality of data recorded in this non-lab setting, we found that 96% of our data were of adequate quality for acoustic analysis based on a threshold of <10dB signal to noise ratio (De Decker 2016:17). We excluded the remaining 4% of tokens from the analysis. Ultrasound data were recorded with a set-up similar to what would be used in a lab setting (see below) and we did not discern any notable reduction in quality compared to lab data. The advantage of collecting data in this context is that we were able to record people who would not usually travel to our lab on campus. Of participants who gave us their postcode during data collection, 31% lived in the lowest decile for multiple deprivation in England and Wales (see discussion and analysis in Nance et al. 2024:9). It is unlikely that we would have been able to collect this demographic with a lab-based approach.

We recorded 64 people in total, including one recording day in Blackburn and one in Burnley. In the auditory and acoustic analyses, we included data from 41 people who said they mainly grew up and lived in Blackburn (18 participants) or Burnley (23). In the articulatory analysis, we included data from 35 participants with good imaging quality (13 from Blackburn and 22 from Burnley). We recorded participants aged 8–88, but we only recorded adults in Burnley. Here, we therefore consider data from participants aged 16–88 in order to ensure comparable data across the two locations. Twenty-six participants were female, and 15 male. Thirty-six of our participants were white British ethnicity. In Blackburn 2/18 participants were British Asian. In Burnley, 3/23 were British Asian. This means our Burnley sample is ethnically representative (at least in terms of the white and British Asian communities), but we were not able to achieve this in Blackburn. Participant occupation was very varied including unemployed, student, mill worker, doctor, artist, council manager, and cleaner. Due to the extent of variation in occupation, we have not analysed this information further. Ethical approval was gained for data collection in Blackburn and Burnley from the Faculty of Arts and Social Sciences Ethics Committee at Lancaster University, reference numbers: FASSLUMS-2022-1060-RECR-1 and FASSLUMS-2023-3965-RECR-1.

3.2 Materials and recording setup

The data were recorded at one of two recording stations using the same software and hardware (see Figure 2 in Nance et al. 2024:5). We recorded simultaneous acoustic and ultrasound data into Articulate Assistant Advanced (AAA; Wrench 2023). We used the Telemed MicrUs system to record our ultrasound data, with a 64-element probe, 20mm radius. The probe frequency was 2MHz, depth was 80mm, and field of view was 90–100% which results in a frame rate of 80–90Hz. The probe was held in place using a plastic helmet (Spreafico et al. 2018). The acoustic data were recorded with a Beyerdynamic Opus 55 headset microphone attached to the helmet. Acoustic data were recorded with a Sound Devices USBPre2 audio interface at 22,050Hz sampling rate. The data were synchronised by recording the TTL (Transistor-Transistor Logic) pulse that the ultrasound emits at the completion of each frame to a simultaneous audio track, meaning that each ultrasound frame is synchronised to the corresponding audio.

Each participant read a list of thirteen words twice. Nine of the words contained instances of potential coda rhoticity, and the remaining four words were distractors or minimal pair counterparts. We aimed to record words which would be well-known to both adults and children and could be represented easily with pictures in case of developing or low literacy skills. Each word was presented with a picture and also orthography in AAA. Words were presented in a fixed random order. The word list is included in Table 1. Note that in Lancashire, the NURSE and SQUARE lexical sets are sometimes merged (Watson & Clark 2013). NORTH and FORCE are merged in east Lancashire (Heselwood 2009; Turton & Lennon 2023). A disadvantage of our data collection method in terms of phonetic analysis is that we needed to keep the data collection time relatively short to ensure that the activity was fun and engaging for the public. As such, the total number of words is relatively low, but we balance that by analysing data from a larger number of individuals than is typical for ultrasound studies. Once the data were cleaned and prepared for analysis, we included 1031 tokens in the auditory and acoustic analyses (Sections 4.1.1 and 4.1.2) and 276 in the comparison of minimal rhoticity pairs (Section 4.2).

Table 1: The word list for this study. 'Typical' productions are included to give an idea of dialect realisations and are based on speakers bl_b01_f and bu_b05_f.

Word	**Lexical set**	**Typical Blackburn production**	**Typical Burnley production**
beard	NEAR	bɪəɹd	bɪəd
cake	FACE	kʰeːk	kʰeːⁱk

farm	START	fɑɹm	fɑm
stair	SQUARE	stɛəɹ	stɛə
fair	SQUARE	fɛəɹ	fɛə
fur	NURSE	fɜ̟ɹ	fɜː
stir	NURSE	stɜ̟ɹ	stɜː
worm	NURSE	wɜ̟ɹm	wɜːm
goat	GOAT	go̞ːt	goːt
caw	THOUGHT	kʰɔː	kʰɔː
paw	THOUGHT	pʰɔː	pʰɔː
core	NORTH/FORCE	kʰɔɹ	kʰɔˤ
pour	NORTH/FORCE	pʰɔɹ	pʰɔˤ

3.3 Rhoticity realisation

Our first research question assesses the extent and character of rhoticity in two communities. To achieve this, we first conducted an auditory analysis to make comparisons with previous sociolinguistic work and also set a baseline for subsequent articulatory and acoustic work. The acoustic data were first exported from AAA into Praat for auditory and acoustic analysis (Boersma & Weenik 2025). Each token was labelled for coda vowel plus any following rhoticity manually. All words containing possible rhoticity were first auditorily coded for presence of absence of rhoticity by the first and second authors. Each coder completed their analysis independently before comparing. Where there was disagreement, the token was reviewed and a final decision made by the first author. In terms of inter-rater reliability, Cohen's kappa (Cohen 1960) indicates 'substantial agreement' (McHugh 2012) for the data from Blackburn and from Burnley. For the Blackburn data, $k = 0.78$, $z = 16.2$, $p <.001$. In the data from Burnley, $k = 0.79$, $z = 16.4$, $p <.001$.

Further data processing was conducted in R and RStudio (R Core Team 2025). We fitted a mixed effects logistic regression model to the auditory coding data. The dependent variable was presence/absence of rhoticity. We included the independent variables of location (Blackburn/Burnley), age (continuous), gender, and interactions of location*age and location*gender. Categorical variables were sum-coded and the continuous variable z-scored. We included random intercepts for speaker and word. Significance testing was carried out by testing the full model against a nested model not containing the predictor of interest via ANOVA (Winter 2020). Due to the correlation between vowel context and word in some cases, we assess the extent of rhoticity in different vowels through inspection of the intercept values for each word. As there are only a small number of non-white speakers in the dataset, we discuss the variation according to ethnicity qualitatively. Regression models were fitted using the lme4 and optimx packages (Bates et al. 2015; Nash & Varadhan 2011), and model output visualised using patchwork and broom.mixed packages (Bolker & Robinson 2018; Pedersen 2019) .

We also conducted an acoustic analysis of the first three formants. These were estimated in Fast Track (Barreda 2021) using the recommended settings i.e. a ceiling range of 4550– 6500 Hz for females and 5000–7000 Hz for males, which are then used to derive optimal by-token LPC orders. The optimal analyses from Fast Track were further processed in R. In order to assess the quality of derhoticising vowels in our study locations, we compared realisations on a vowel-by-vowel basis by fitting a GAMM (Generalised Additive Mixed Model) to the values of F3–F2 across 11 time-normalised points in the vowel(+rhoticity) interval (Wood 2017). We chose F3–F2 as this has previously been shown as the important perceptual correlate for rhoticity in Lancashire (Heselwood 2009). The GAMMs were fitted following Sóskuthy (2017). The predictor variables included a parametric term for location (Blackburn/Burnley), and smooth terms for time and time*location interaction. We included random smooths of time-by-speaker and time-by-word. To conduct significance testing, we first compared the full autoregressive model to a nested model excluding predictors for location in order to assess differences by trajectory height. We then compared the full model to a model excluding rhoticity-by-time to investigate differences in trajectory shape (following the method in Kirkham et al. 2019). We did not include gender in this modelling for the following reasons: the auditory analysis showed no difference for gender, F3–F2 will normalise for expected speaker sex differences in formant values to some extent (Turton & Lennon 2023), and this strategy simplifies the modelling approach in order to fit GAMM models. GAMMs were fitted using the mgcv and itsadug packages and visualised using tidygam (Coretta 2023; Wood 2004; van Rij et al. 2022).

The labelled TextGrid files from the auditory and acoustic analyses were then reimported into AAA to serve as landmarks for the articulatory analysis. Tongue splines were generated using the DeepLabCut plug-in for AAA (Wrench & Balch-Tomes 2022). Spline coordinates were then extracted from 11 equally spaced timepoints across the vowel(+rhoticity) interval. Coordinates were rotated to each participant's occlusal plane using a recording made with a bite plate (Scobbie et al. 2011). The Cartesian coordinates were z-scored within speakers in order to locate each speaker's values on visually comparable scales. To answer the articulatory component of our first research question, we focus on tongue shape in two minimal pairs: core, caw and pour, paw. Here, we present a visual comparison of tongue shapes at 80% of the vowel(+rhoticity) duration (i.e. the ninth out of the 11 timepoints). In this figure, the raw DLC output was smoothed with a Butterworth filter (see code and data 'tongue_plot_prep' script). For statistical analysis of articulatory data, see Section 3.4.

3.4 Articulation of derhoticisation

To further assess the nature and extent of derhoticisation across east Lancashire, we conducted quantitative analysis of the tongue shapes used in the minimal pairs core, caw and pour, paw. In the quantification of tongue shapes, several previous studies have used Principal Component Analysis (PCA) to capture variation in the shape of the tongue (x and y coordinates) and translate the curved shape into numeric values for statistical analysis (Stone 2005; Nagamine 2025). The advantage of this method is that tongue shapes can be reconstructed from the PCA output in order to interpret the coefficients. Here, we use Functional PCA (FPCA) in order to account for the relationship between coordinates along the tongue surface (Gubian, Torreira & Boves 2015; Ramsay & Silverman 2005). We fitted a Multivariate FPCA in order to account for variation in x coordinates and also y coordinates following the method in Coretta & Sakr (2026). In our analysis, we fitted the MFPCA to tongue splines from the 11 time-normalised points in the vowel(+rhoticity) interval. In this way, we use PCA to account for time-varying information across the syllable as well as the shape of the tongue (Nagamine 2024).

To interpret the PCA output, we reconstructed tongue shapes and interpret the PC scores. This is done by multiplying increments of the standard deviation for each PC by the intercept of that PC function and adding to the mean tongue shape (Johnson 2011; Coretta & Sakr 2026) PCA produces multiple principal components which capture ever decreasing amounts of variation in a dataset. Here, we analyse the first four components as these explained over 85% of the total variation in the data (Jolliffe & Cadima 2016), mapped on to interpretable tongue movements, and analysis of a scree plot indicates a clear elbow after PC4 (see code and data). In the first model we fitted, PC1 accounts for 39% of the variation, PC2 25%, PC3 15%, and PC4 8%. As recommended in Coretta & Sakr (2026), we then fitted another MFPCA with only the components of interest. In this model, PC1 accounts for 46% of the variation, PC2 29%, PC3 17%, and PC4 9%. We extracted the PC scores and associated information about each speaker, token, and word, and fitted a GAMM as described above for the acoustic analysis. In this way, variation in the tongue shape over time can be visualised and analysed statistically. Each model tested the PC scores for PCs 1–4, a parametric term for minimal pair (*core/pour* vs. *caw/paw*), and smooth terms for time and time*minimal pair interaction. We included random smooths of time-by-speaker and time-by-word. Significance testing was conducted by model comparison as described for the acoustic analysis (Section 3.3). Our model comparison assesses for differences in trajectory height, and differences in trajectory shape. Where there are differences in trajectory height, we assume that the community in that location distinguishes the minimal pair by a difference in gestural magnitude. Where there are differences in trajectory shape, we assume that the community in that location distinguishes the minimal pair by a difference in gestural timing.

4 RESULTS

4.1 Rhoticity realisation

4.1.1 Rhoticity realisation: Auditory

In terms of auditory quality, the rhoticity in Blackburn and Burnley is mainly pharyngealisation or occasional alveolar approximants. Dickson & Hall-Lew (2017:240) describe a continuum of derhoticising variants from trill to secondary pharyngealisation (see Table 2). The variants we encountered are derhoticised or non-rhotic. Some participants produced schwa offglides as a trace of some kind of former rhoticity. We have not included schwa offglides as ‘rhotic’ in this analysis as there is no audible /r/-like quality in these tokens. Examples from our data of audible and non-audible rhoticity in the same word are shown in Figure 2.

Table 2: Continuum of derhoticisation adapted from Dickson and Hall-Lew (2017).

trill	**tap**	**schwar**	**retroflex approximant**	**alveolar approximant**	**derhoticised**	**no /r/**
[r]	[ɾ]	[ɚ]	[ɻ]	[ɹ]	[Vˤ]	Ø
most rhotic	→	→	→	→	→	least rhotic

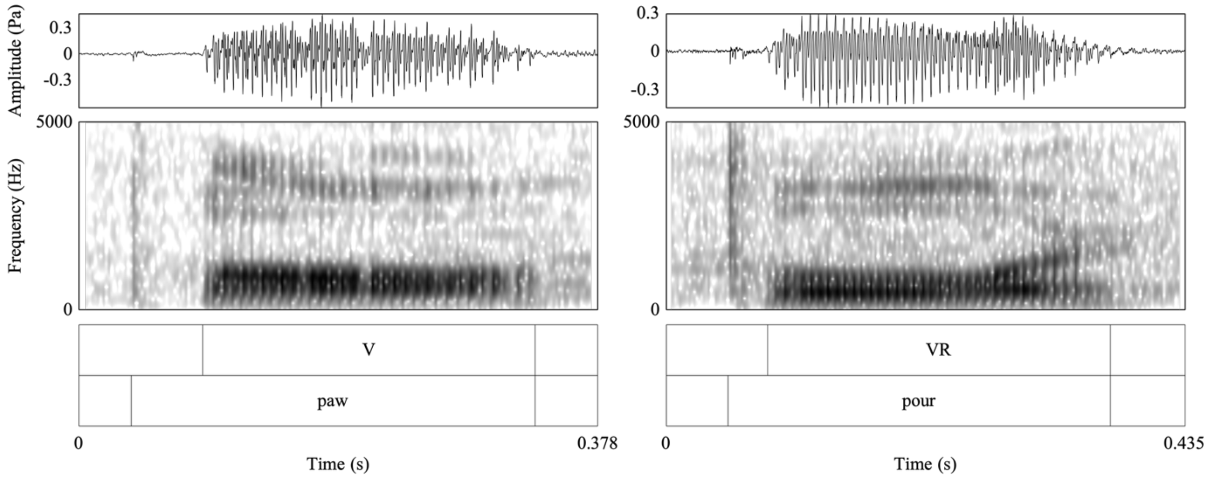

Figure 2: An example minimal pair which contrast for rhoticity, ‘paw’ and ‘pour’, produced by a male speaker from Blackburn. On the right side of the ‘pour’ spectrogram, there is a clear rise in F2 and drop in F3.

The results of the logistic regression modelling of the auditory data are shown in Table 3. The modelling shows that there is a significant difference between Blackburn and Burnley in amount of audible rhoticity. The results for individual speakers are shown in Figure 3. This figure indicates that there are more speakers in Blackburn who are categorically rhotic in every possible context, and also more speakers in Blackburn who are variably rhotic. We did not find an effect of age in this dataset. Previous analysis only of the Blackburn data included children in our sample (Nance et al. 2023). When we did this, age significantly predicted rhoticity realisation with older speakers more rhotic than younger. There is a trend towards this finding in our current analysis, with the only two categorically non-rhotic participants in Blackburn being the youngest speakers in the dataset. There are no significant differences for gender, or for the interactions we modelled.

Table 3: Results of logistic regression modelling on the auditory coding.

Full model				
intercept	$\widehat{\boldsymbol{\beta}}$	**SE($\widehat{\boldsymbol{\beta}}$)**	z	$p(z)$
	-1.16	0.81	-1.44	.15

Fixed effects	***df***	$\boldsymbol{\chi^2}$	$\boldsymbol{p(\chi^2)}$
Location	3	16.94	**<.001**
Age	2	4.87	.09
Gender	2	3.88	.14
Location*age	1	1.93	.17
Location*gender	1	3.13	.08

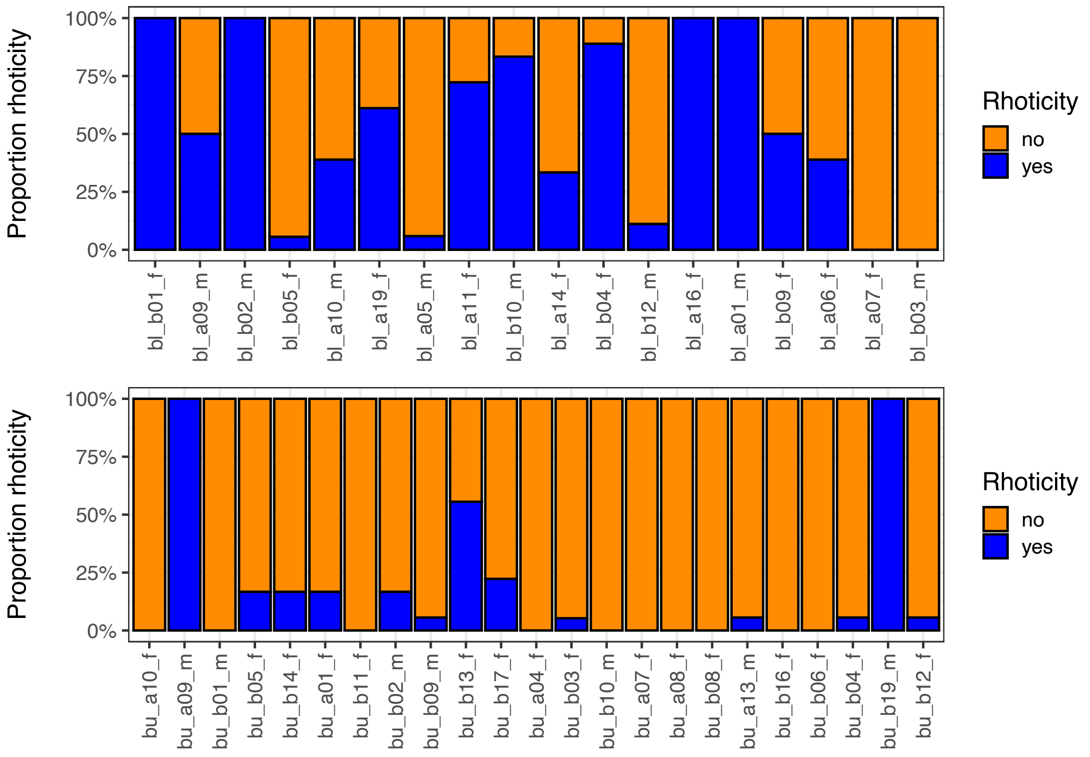

Figure 3: Proportion of audible rhoticity for individual speakers in Blackburn (top), and Burnley (bottom). Speakers are arranged from oldest on the left to youngest on the right. Gender is included in each speaker's code as well as location and which ultrasound machine we used to record them ('a' or 'b').

The random intercepts for each word are plotted in Figure 4, left panel. The figure shows that rhoticity is favoured in the words 'pour', 'core' and 'farm' (THOUGHT and START lexical sets) and disfavoured in 'stair' and 'fair' (SQUARE set). Variation according to ethnicity is plotted in Figure 4, right panel. Here, we pooled the data from both locations. Note there are two British Indian participants, two British Pakistani, one British Bangladeshi and 36 White British. The British Indian participants produced a substantial amount of rhotic tokens, over 50%. Rhoticity was realised as a trill and we consider this an influence from Indian English. There were no other trills in the dataset. The British Pakistani and Bangladeshi speakers produced almost no rhotic tokens.

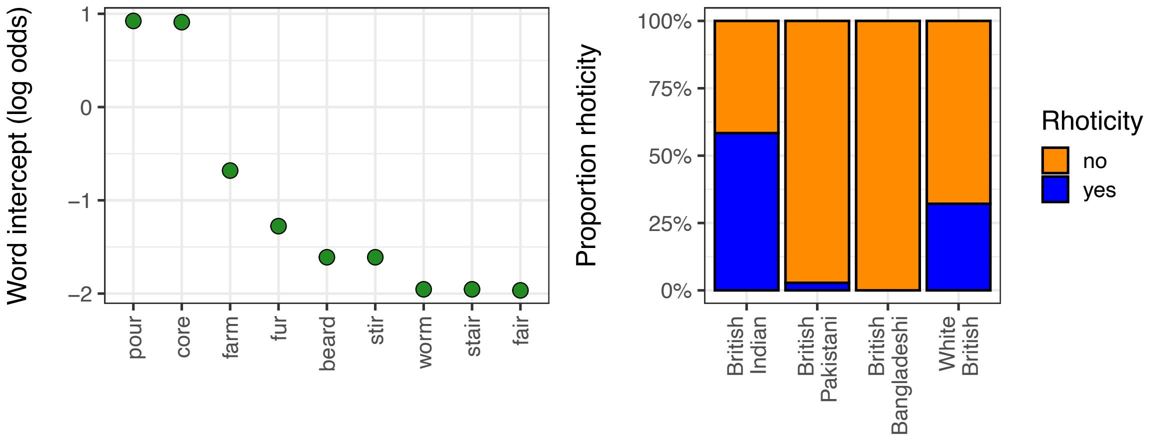

Figure 4: Random intercepts for the auditory analysis of each word (left panel), and proportion of rhoticity for speaker ethnicity (right panel).

4.1.2 Rhoticity realisation: Acoustic

Here, we assess the acoustic quality of vowel(+rhoticity) in different vowels in Blackburn and Burnley. The results of the GAMM model comparisons are shown in Table 4. As recommended by (Sóskuthy 2017:17), we have used the model comparisons for significance testing, rather than visualisation of the models. To illustrate our modelling, we have shown the output in Figure 5. The analysis in Table 4 shows significant differences for trajectory height in NURSE, START and NEAR words, and significant differences for trajectory shape in START words. Figure 5 shows that F3–F2 is lower in Blackburn NURSE, START and NEAR words. The lack of significant shape differences in NURSE and NEAR words indicates that F3–F2 is lower throughout the vowel(+rhoticity) interval. In start words, the significant difference for trajectory shape indicates that F3–F2 is lower, but only in the latter part of the vowel(+rhoticity) interval.

Table 4: Results of GAMM modelling for different dialects.

Lexical set	**Trajectory height**			**Trajectory shape**		
	χ^2	*df*	$p(\chi^2)$	χ^2	*df*	$p(\chi^2)$
NORTH/FORCE	0.41	3	.85	0.39	2	.68
NURSE	6.50	3	**.005**	0.71	2	.49
SQUARE	3.07	3	.12	1.99	2	.14
START	5.61	3	**.01**	4.84	2	**.008**
NEAR	5.56	3	**.01**	0.30	2	.74

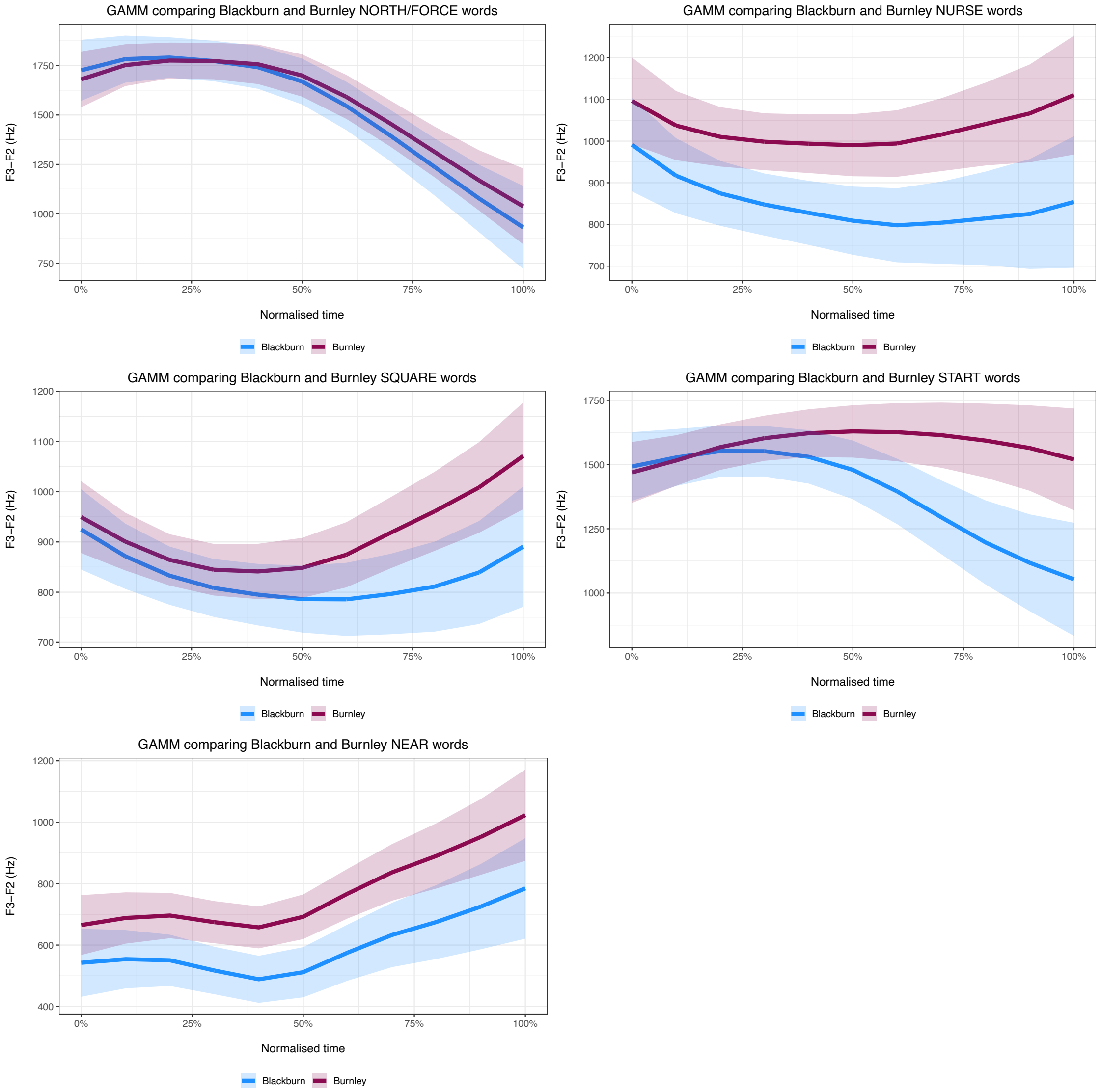

Figure 5: Visualisations of the GAMM models for F3–F2 in Blackburn (blue) and Burnley (claret). For significance testing, see Table 4.

4.1.3 Rhoticity realisation: Articulatory

This section aims to describe vowel(+rhoticity) articulation in Blackburn and Burnley, for holistic statistical analysis see Section 4.2. Figure 6 plots tongue shapes for the minimal pairs *core~caw* and *pour~paw* at 80% of the vowel(+rhoticity) interval. The speakers are grouped according to the auditory analysis of their productions:

categorically rhotic (in *core, pour*), categorically non-rhotic, or variable. The figure indicates that audible rhoticity generally corresponds to productions with a raised tongue tip. One speaker, bu_b13_f, consistently produced a bunched /r/. One speaker who is audibly consistently rhotic, bu_b17_f, does not appear to produce separate tongue shapes for the minimal pair. It is possible that the selected timepoint did not capture different tongue shapes for this speaker's productions, or that they are using lip rounding to produce a percept of rhoticity which would not be captured by our methods. Speakers bu_b01_m, bu_a10_f, and bu_b01_m appear to produce separate tongue shapes but were not perceived as producing rhoticity. In the speakers who were variably auditorily rhotic, bl_b05_f seems to produce identical tongue shapes for all words, and speaker bu_b05_f produced very separate *core/pour* vs. *caw/paw*, but the auditory percept is variable. This analysis indicates that there is not necessarily a one-to-one correspondence between what is heard as rhoticity and tongue shape. For this reason, we conducted a more in-depth analysis of tongue shape in Section 4.2.

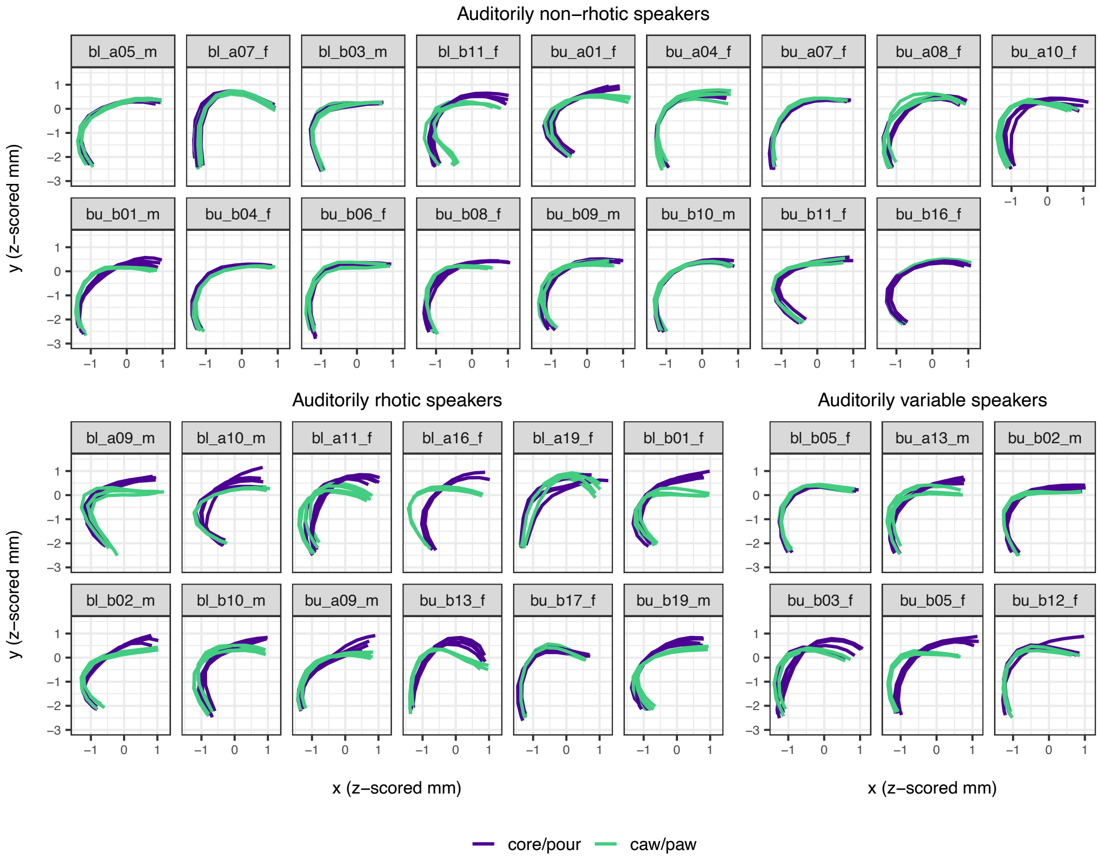

Figure 6: Tongue shapes at 80% duration of the vowel(+rhoticity) interval in minimal pairs *core~caw* and *pour~paw*. Blackburn speaker labels begin with ‘bl’ and Burnley with ‘bu’. The letters ‘a’ and ‘b’ refer to our two recording stations.

4.2 Articulation of derhoticisation

We first reconstructed the tongue shapes based on the PC scores and standard deviations. These are shown in Figure 7. PC1 corresponds to movement in the front part of the tongue and we refer to this as ‘tongue tip’ for shorthand. PC2 corresponds mainly to movement in tongue body height (as well as tongue root), PC3 to tongue fronting/backing, and PC4 to movement in the tongue root. The results of the GAMM models for each dialect are in Table 5. In Blackburn, the minimal pairs for rhoticity are distinguished by tongue tip trajectory height and shape, tongue frontness trajectory height and shape, and tongue root trajectory height. In Burnley, the minimal pairs are only distinguished by tongue tip trajectory shape and height, and tongue frontness trajectory height. Visualisations of the model output are shown in Figure 8. We focus on PC1, PC3, and PC4 where there were significant differences. Figure 8 illustrates the substantial dialect difference in PC4, tongue root. In Blackburn, the tongue root is retracted for *core/pour* but not in *caw/paw*. There is no corresponding difference in Burnley.

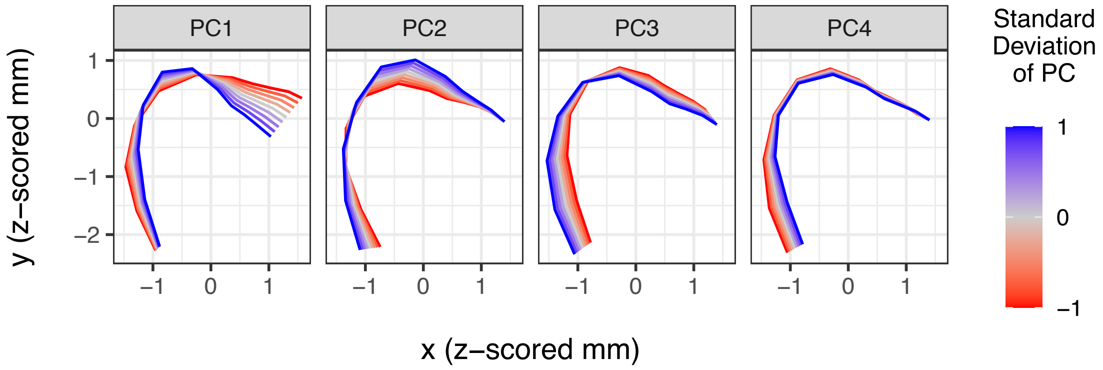

Figure 7: Reconstructed tongue shapes based on different fractions of the standard deviation for each PC.

Table 5: Results of GAMM modelling for different dialects.

PC	**Dialect**	**Trajectory height**			**Trajectory shape**		
		χ^2	*df*	$p(\chi^2)$	χ^2	*df*	$p(\chi^2)$
1 (tongue tip)	Blackburn	16.54	3	**<.001**	13.72	2	**<.001**
2 (tongue height)	Blackburn	1.11	3	.53	0.87	2	0.42

3 (tongue frontness)	Blackburn	7.96	3	**.001**	3.88	2	**.02**
4 (tongue root)	Blackburn	9.62	3	**<.001**	2.33	2	.10
1 (tongue tip)	Burnley	11.71	3	**<.001**	9.71	2	**<.001**
2 (tongue height)	Burnley	3.62	3	.07	0.32	2	.73
3 (tongue frontness)	Burnley	8.12	3	**<.001**	1.64	2	.19
4 (tongue root)	Burnley	1.96	3	.27	0.15	2	.86

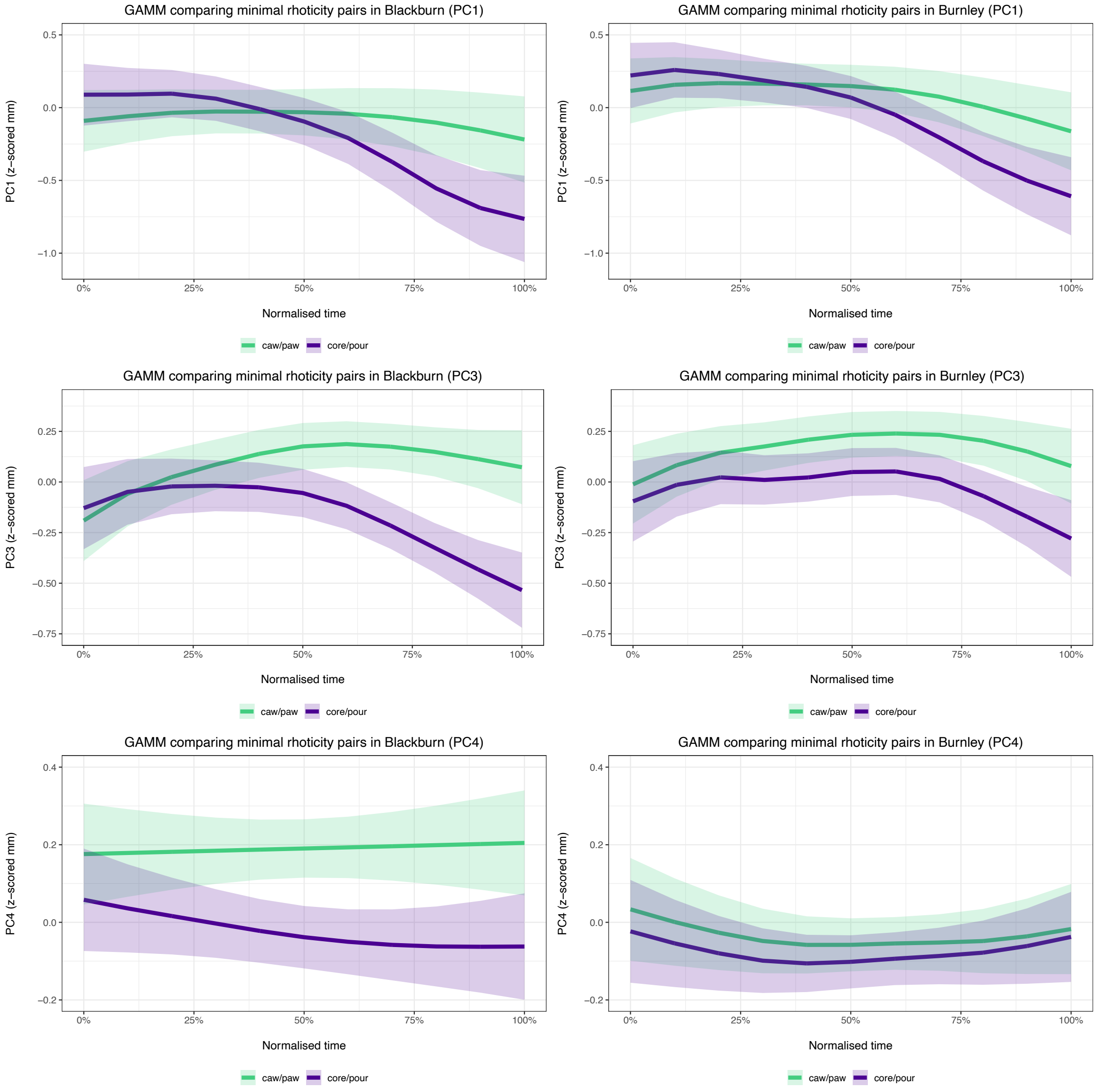

Figure 8: GAMMs comparing PCs for minimal rhoticity pairs in each dialect. We focus on PC1, PC3, and PC4 which gave significant results, see Table 5.

4.3 Results summary

Our first analysis indicates significant differences in auditory rhoticity between Blackburn and Burnley. Blackburn speakers are more rhotic, especially in thought and start vowels. British Indian participants produced trilled rhotics, but British Bangladeshi and British Pakistani speakers were non-rhotic. There were no significant differences for age or gender. Our acoustic analysis compared the trajectory of F3–F2 in each dialect per vowel. Blackburn speakers produced more rhoticity (F3–F2 is lower) in NURSE, START and NEAR words, with differences at the end of START words only. Visualisation of tongue shapes at 80% of the vowel(+rhoticity) interval indicates that most rhotic speakers produce tip up tongue gestures for the rhotic.

Our second analysis focussed on the articulation of minimal pairs of rhoticity, and differences by dialect in how this contrast is realised across the vowel(+rhoticity) interval. This analysis revealed dialect-specific differences in PC3 (tongue fronting) and PC4 (tongue root). In the production of minimal pairs, Burnley speakers do not significantly differentiate PC3 trajectory shape, nor PC4 shape or height. We interpret this as dialect differences in the magnitude of the tongue fronting gesture (PC3), and a dialect-specific difference in both timing and magnitude of the tongue root gesture (PC4).

5 DISCUSSION

In this paper, our aim was to examine variation in two closely related dialects as a window into the diffusion of sound change. In particular, we focus on the articulatory mechanisms at play in the diffusion of derhoticisation, where there are complex acoustic-articulatory-perceptual relationships. Here, we first discuss the cross-dialectal descriptive findings, providing evidence for the spread of derhoticisation as this sound change proceeds towards completion in Lancashire. Second, we discuss the articulatory mechanisms behind the change, and implications for understanding community-level variation in the diffusion of change.

5.1 Realisation of derhoticisation

Our auditory analysis confirmed perceptions and dialectological surveys that there is lesser rhoticity in Burnley than in Blackburn. For example, Figure 1 in Leemann et al. (2018, p. 12) indicates a spot of rhoticity in Blackburn, but lower rates in Burnley. Similarly, smaller-scale studies in east Lancashire note greater rates of rhoticity in Blackburn and Rossendale, but less in Burnley (Austin 2007; Vivian 2000). In this analysis, we only included data from adults and did not find differences for age in rates of rhoticity. However, previous work including children did find a significant difference for age, where younger speakers are less rhotic (Nance et al. 2023). Similarly, analysis of rhoticity in Blackburn indicates age-related differences and lower rhoticity in younger generations (Turton & Lennon 2023; Turton & Lennon Under review). Younger speakers in our dataset were among the least rhotic, so it seems likely that this change is still in progress across generations, but we did not have enough speakers in each cohort to achieve a significant result.

We provided a qualitative discussion of ethnicity variation in our data and found that British Indian participants produced trilled rhotics, and British Bangladeshi and British Pakistani participants were non-rhotic. This is similar to other reports of British South Asian speakers from east Lancashire (Rabani 2024). In terms of vowel context, the most audibly rhotic words in the dataset were words in the NORTH/FORCE lexical set, ‘core’ and ‘pour’. Previous studies of rhoticity in England have found the NURSE contexts are generally most rhotic (Blaxter et al. 2019; Piercy 2012), although the review in (Blaxter et al. 2019:99) notes substantial variation across studies. Previous variationist work in Lancashire has largely been acoustic (Dann, Ryan & Drummond 2022; Ryan, Dann & Drummond 2022; Turton & Lennon 2023), but auditory analysis in Barras (2010:176) and Turton & Lennon (Under review) also find that /ɔː/ contexts are most rhotic.

Acoustic analysis allowed us to investigate the vowel contexts and positions where there are dialect differences in more detail. By measuring F3–F2 it is expected that the different lexical sets will have different values so in this case we modelled each one separately with GAMMs to investigate dynamic differences in formants for each dialect. There were significant differences for trajectory height in three vowel contexts: NURSE, START, NEAR and an additional difference for trajectory shape in START. This analysis indicates that there are acoustic differences for dialect in rhoticity for NURSE, START, NEAR, with Blackburn being more rhotic. The dynamic perspective allows us to conclude that Blackburn is more rhotic right across the vowel(+rhoticity) interval in NURSE and NEAR words, and more rhotic only at the end of START words.

The descriptive analysis of articulation presented in Figure 6 shows different tongue shapes are used by the speakers who are audibly rhotic in the realisation of minimal pairs for rhoticity. This analysis shows that the majority of rhotic speakers use tip-up gestures for realising rhotics, although one speaker uses a bunched rhotic. In their analysis comparing realisation of rhoticity across social classes in Scotland, Lawson, Scobbie & Stuart-Smith (2011) found socially stratified differences in tongue shape. Specifically, middle class speakers mainly used bunched rhotics, and working-class speakers used tip-up gestures. In their case, middle class speakers are strongly rhotic, and working-class speakers produced derhoticised variants. Our speakers appear to be more like these working-class Scottish speakers and produced variants audibly resembling pharyngealisation. This is similar to the end stage of rhoticity loss in Dickson & Hall-Lew (2017), see Table 2. We suggest that a tip-up tongue shape with accompanying tongue root retraction is characteristic of derhoticising variants also in east Lancashire.

Rhoticity loss has led to large vowel changes in quality and quantity across different varieties of English (Hickey 2025). In the case of east Lancashire Englishes, many of these vowel changes are already complete and the system resembles non-rhotic Lancashire varieties, with some residual rhoticity. As rhoticity loss continues, it seems likely that minimal pairs in the lexical sets commA~lettER, PALM~START, and THOUGHT~NORTH/FORCE will become homophonous as they are for non-rhotic Lancashire Englishes, for example *tuna~tuner, spa~Spar*, and *caw~core*.

5.2 Articulation at the end stage of sound change

Our articulatory analysis allowed in-depth investigation of the mechanisms behind derhoticising variants across communities. The aim of this analysis was to ascertain if the articulatory processes involved in sound change actuation can also be found in sound change diffusion. In Section 2.3, we hypothesised that communities with differing audible levels of rhoticity would use gestures of differing magnitude and timing in the rhoticity contrast. The GAMM analysis of FPCA scores in rhoticity minimal pairs allowed us to investigate dialect differences in tongue gesture magnitude (trajectory height) and dialect differences in tongue gesture timing (trajectory shape). We found dialect differences in PC3, which corresponds to tongue fronting. Specifically, Burnley speakers do not differentiate minimal pairs for tongue fronting timing, and do not differentiate minimal pairs in tongue root (PC4) gestural magnitude or timing.

These differences indicate that in Burnley the tongue is more front in rhotic words (note this is a back vowel context), but there is no movement in tongue frontness across the syllable as there is in Blackburn. In Burnley, there are no differences for tongue root movement in rhotic words compared to non-rhotic words. This indicates that there is lesser pharyngealisation in Burnley rhoticity and this is the case right across the syllable. Blackburn speakers on the other hand displayed retracted tongue root in rhotic words right across the syllable (no differences for trajectory shape in Blackburn). In terms of the articulatory correlates of the progression of sound change, the lesser rhoticity revealed by our auditory analysis is realised by differences in tongue root gesture. Burnley speakers do not use the tongue root to distinguish between rhotic and non-rhotic minimal pairs. Our analysis supports gestural reduction and some evidence for a change in timing: Burnley speakers do not adjust the height of the front of the tongues across rhotic codas, while Blackburn speakers do.

Our analysis employs a variety of methods and perspective to shed light on the progression of sound change across geographic communities (Lawson, Scobbie &

Stuart-Smith 2014). In doing so, we observe some similar patterns to previous work which has considered variation within geographic locations. For example, social class comparisons in eastern central Scotland indicate stratified differences in tongue shape where working-class speakers who are derhoticising use tip up gestures and tongue root retraction, but middle-class speakers use bunched articulations (Lawson, Scobbie & Stuart-Smith 2011). Further analysis revealed that the primary articulatory mechanism for social class variation in Scottish derhoticisation is a difference in gestural timing (Lawson, Stuart-Smith & Scobbie 2018). Our participants represent a stage further along on a continuum to non-rhoticity (Dickson & Hall-Lew 2017). Most of our rhotic speakers produce articulations with tip-up gestures (Figure 6), but Burnley speakers do not use tongue root retraction to distinguish minimal pairs for rhoticity (Table 5). This suggests that Burnley is a stage further along in the progression of sound change compared to Blackburn or working-class eastern Scotland. Similarly, Turton & Lennon (Under review) find articulatory differences across generations in Blackburn. Specifically, they find age-related differences in the height of the front of the tongue, where younger speakers have differences in tongue front gestural magnitude compared to older speakers, but tongue root position remains stable across generations. This is similar to our finding for PC3 in Burnley compared to Blackburn.

6 CONCLUSIONS

Our aim was to understand the articulatory mechanisms in the diffusion of a major sound change in English. Articulation has long been cited as a source for the actuation of sound change (Ohala 1989; Beddor et al. 2018) but is less investigated in sound change diffusion (Cunha et al. 2024; Lawson, Stuart-Smith & Scobbie 2018; Stuart-

Smith, Lawson & Scobbie 2014; Turton & Lennon Under review). We focussed on rhoticity loss as the nexus of complex perceptual-acoustic-articulatory relationships in order to gain a picture of possible mismatches and in these relationships. Similar to Cunha et al. (2024)'s articulatory investigation of nasalisation across closely related dialects, we aimed to understand patterns of articulatory mechanisms across communities.

In the realisation of lessening perceived rhoticity, we found dialect differences in timing of the tongue front gesture and reduction in magnitude and timing differences in the tongue root, supporting our hypotheses. Studies of derhoticisation often cite the numerous, and at times contrasting, acoustic and perceptual cues for loss of rhoticity (Sóskuthy & Stuart-Smith 2020; Turton & Lennon 2023). We suggest that the process of derhoticisation can be modelled similarly to sound change actuation, through degrees of change in gestural magnitude or timing (Browman & Goldstein 1991; Bybee 2012:228). However, due to the multiple lingual articulations, (as well as labial gestures which were not considered in this study), the outcome of rhoticity loss can appear varied acoustically and perceptually. In our case, we considered the very end stage of sound change and indeed several of the speakers in our dataset were not audibly rhotic. At this stage, community-level differences in tongue root seem to be the signature of remaining stronger rhoticity in Blackburn. We predict that a larger cross-community comparison encompassing multiple communities at differing stages of this sound change would exhibit different acoustic and articulatory realisations corresponding to differing gestural magnitude and timing patterns for the lingual and other articulators at play in the realisation of rhoticity.

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