

**Dialect variation in formant dynamics: The acoustics of lateral and vowel sequences  
in Manchester and Liverpool English**

Sam Kirkham,<sup>1, a)</sup> Claire Nance,<sup>1</sup> Bethany Littlewood,<sup>1</sup> Kate Lightfoot,<sup>1</sup> and Eve  
Groarke<sup>1</sup>

*Department of Linguistics and English Language, Lancaster University,*

*County South, Lancaster LA1 4YL, United Kingdom*

1 This study analyses the time-varying acoustics of laterals and their adjacent vowels  
2 in Manchester and Liverpool English. We use Generalized Additive Mixed-Models  
3 (GAMMs) for quantifying time-varying formant data, which allows us to model non-  
4 linearities in acoustic time series while simultaneously modelling speaker and word  
5 level variability in the data. We compare these models to single time-point analyses  
6 of lateral and vowel targets in order to determine what analysing formant dynamics  
7 can tell us about dialect variation in speech acoustics. The results show that lateral  
8 targets exhibit robust differences between some positional contexts and also between  
9 dialects, with smaller differences present in vowel targets. The time-varying anal-  
10 ysis shows that dialect differences frequently occur globally across the lateral and  
11 adjacent vowels. These results suggest a complex relationship between lateral and  
12 vowel targets and their coarticulatory dynamics, which problematizes straightforward  
13 claims about the realization of laterals and their adjacent vowels. We further discuss  
14 these findings in terms of hypotheses about positional and sociophonetic variation.  
15 In doing so, we demonstrate the utility of GAMMs for analysing time-varying multi-  
16 segmental acoustic signals, and highlight the significance of our results for accounts  
17 of English lateral typology.

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<sup>a)</sup>[s.kirkham@lancaster.ac.uk](mailto:s.kirkham@lancaster.ac.uk)

## 18 I. INTRODUCTION

### 19 A. Variation in English laterals

20 The present study aims to quantify time-varying acoustic patterns in lateral and vowel  
21 sequences and, secondarily, to determine the nature of dialect differences and positional  
22 contrast in the lateral systems of two varieties of British English (Manchester and Liverpool).  
23 The allophony of English lateral production is most commonly framed in terms of ‘clear’  
24 versus ‘dark’ allophones of /l/ (Recasens, 2012), and the presence or absence of positional  
25 variants (Sproat and Fujimura, 1993). The terms ‘clear’ and ‘dark’ represent abstractions  
26 on different ends of a continuum (Recasens and Espinosa, 2005). Articulatorily, clear /l/s  
27 involve raising and fronting of the tongue body, while dark /l/s involve tongue dorsum  
28 lowering and retraction (Narayanan *et al.*, 1997; Recasens and Espinosa, 2005). Clear /l/s  
29 also typically involve the tongue tip gesture occurring simultaneous with (or prior to) the  
30 tongue dorsum gesture, whereas dark /l/s typically show tongue dorsum retraction prior to  
31 the tongue tip gesture (Sproat and Fujimura, 1993). Lateral clearness-darkness has also been  
32 conceptualised as a single gesture in terms of amounts of predorsum lowering and postdorsum  
33 retraction (Recasens and Espinosa, 2005). These complex articulatory and timing relations  
34 and how they interact with the surrounding vowels make the time-varying nature of lateral  
35 production highly significant (see Section IB).

36 In terms of acoustic consequences, clear laterals typically have high F2 and low F1, while  
37 dark laterals have low F2 and high F1 (Carter and Local, 2007; Ladefoged and Maddieson,  
38 1996; Lehiste, 1964; Recasens, 2012). Accordingly, many studies have used the F2 minus

39 F1 measure ( $F2-F1$ ) to quantify lateral quality, with higher values indicating clearer /l/s  
40 (Carter, 2002; Kirkham, 2017; Lehiste, 1964; Nance, 2014; Sproat and Fujimura, 1993; Tur-  
41 ton, 2014).  $F3-F2$  is also typically higher for darker /l/ than for clearer /l/, due to a low  
42 F2 and high F3 (Recasens and Espinosa, 2005).

43 In the context of British English dialect typology, Southern British English is described as  
44 having clear /l/ in syllable-onsets and dark /l/ in syllable-rimes (Wells, 1982, 370), resulting  
45 in positional contrast between word-initial and word-final productions. However, many  
46 British English varieties do not show such strong positional effects and may display dark  
47 /l/s in all positions, such as Leeds, while others show clearer /l/s in all positions, such as  
48 Newcastle (Carter and Local, 2007). Within dark /l/ varieties, there is also a distinction  
49 between those that show positional differences between initial and final /l/ (e.g. Leeds) and  
50 those that do not (e.g. Sheffield) (Kirkham, 2017). There are other dialects that occupy a  
51 more contested status on the clear-dark continuum, as will be discussed below.

52 The dialects in this study are Liverpool English and Manchester English. Liverpool and  
53 Manchester are both located in the north west of England and are only 35 miles apart by  
54 road. However, these two dialects are reported to be extremely different, with Liverpool in  
55 particularly being one of the most distinctive accents in England (Baranowski and Turton,  
56 2015; Nance *et al.*, 2015; Watson, 2007). In terms of laterals, Manchester English is widely  
57 described as having dark /l/s in all positions (Carter, 2002; Kelly and Local, 1986; Turton,  
58 2014). Turton (2014) reports that middle-class speakers produce an acoustic and articulatory  
59 contrast between initial and final /l/, whereas working-class speakers do not.

60 The realization of Liverpool /l/ is less documented and its status is contested in the  
 61 literature. Jones (1966, 92) speculates that Liverpool /l/ may be clear in all positions,  
 62 stating that ‘its existence there is probably due to Irish influence’, with many varieties of  
 63 Irish English having very clear /l/s. Knowles (1973, 256) claims that /l/ in Liverpool is  
 64 frequently ‘velarised’ and produced in similar ways across positions. One of the few sources  
 65 of instrumental data on Liverpool /l/ comes from Turton (2014), who reports acoustic  
 66 and ultrasound data on a single male speaker. She finds that he produces the initial~final  
 67 contrast in /l/, but that he also produces word-final /l/ with distinct velarisation, as opposed  
 68 to the more pharyngealised articulations documented for other British English varieties. This  
 69 also suggests a potentially ‘intermediate’ realization for Liverpool /l/, which may lie towards  
 70 the middle of a continuum between clear and dark.

71 In this study, we address the relationship between time-varying lateral and vowel formant  
 72 dynamics. Accordingly, we briefly overview previous research on vowels in each variety.  
 73 Manchester English shows features typical of many northern Englishes, such as the lack of a  
 74 FOOT-STRUT or TRAP-BATH split and monophthongal productions of canonical diphthongs  
 75 (Baranowski and Turton, 2015). Liverpool English typically merges the NURSE and SQUARE  
 76 vowels (Knowles, 1973; Watson, 2007) and has complex patterns of raising in PRICE and  
 77 MOUTH before nasal-obstruent clusters (Cardoso, 2015).

78 A concrete difference between dialects that we predict will have an effect on our results is  
 79 the final vowel in words such as *belly* (Wells 1982 calls this the HAPPY vowel). Manchester is  
 80 reported to produce very low and back variants of HAPPY (Baranowski and Turton, 2015),  
 81 which we do not expect to see in Liverpool. Finally, we discuss pre-lateral vowels, which are

82 particularly significant for our study. Fronting of /u/ is typically inhibited before coda /l/ in  
 83 some varieties of English (Kleber *et al.*, 2011), although the articulatory interpretation of this  
 84 is not straightforward (Strycharczuk and Scobbie, 2017). However, Baranowski (2017) finds  
 85 a clear social class effect on pre-lateral /u/ fronting in Manchester, with a strong negative  
 86 correlation between social class and fronting in this context. While we are not aware of any  
 87 studies of pre-lateral /u/ in Liverpool, our own impressions suggest that fronting of /u/  
 88 before coda /l/ is widespread in this dialect.

## 89 B. Time-varying spectral analysis

90 The significance of the time-varying properties of sonorant sounds has been comprehen-  
 91 sively documented in the literature (Elvin *et al.*, 2016; Fox and Jacewicz, 2009; Strycharczuk  
 92 and Scobbie, 2017; Watson and Harrington, 1999; Williams and Escudero, 2014). This is  
 93 particularly pertinent to a study of laterals, which are inherently non-static due to the tim-  
 94 ing relations outlined in Section IA, as well as the existence of strong interactions between  
 95 laterals and the surrounding vowels. This interaction also makes it challenging to place  
 96 reliable segmental boundaries between a lateral and any adjacent vowels. This is even more  
 97 pronounced when comparing clear and dark laterals, which vary in terms of their acoustic  
 98 structure (Recasens and Espinosa, 2005), transitions into and out of the steady-state of the  
 99 lateral phase, and duration of the steady-state phase (Carter, 2002).

100 The above findings have theoretical and methodological implications for how to treat  
 101 adjacent lateral and vowel targets. Many studies have isolated the lateral target by identify-  
 102 ing an F2 steady-state and then more holistically analysed syllable-level formant transitions

103 across the lateral and surrounding vowels (Carter and Local 2007; Kirkham 2017; Nance  
104 2014; Stuart-Smith *et al.* 2015). However, the relationship between lateral targets and ad-  
105 jacent vowel targets is not necessarily straightforward, as we expect a strong coarticulatory  
106 relationship between them, especially for clearer initial /l/s (Recasens and Espinosa, 2005).  
107 Therefore, a primary aim of this study is to analyse lateral and vowel sequences in terms  
108 of (i) steady-state targets for adjacent laterals and vowels; (ii) time-varying formant dy-  
109 namics across the sequence of both segments. This allows us to establish whether patterns  
110 of dialect variation can be captured by targets alone, or whether time-varying information  
111 further contributes to dialect differences.

112 Previous research on lateral formant trajectories has quantified non-linear differences us-  
113 ing methods such as Smoothing-Spline ANOVA (SS-ANOVA) (Kirkham, 2017; Nance,  
114 2014; Simonet *et al.*, 2008). Such methods fit smooth functions to the data using a  
115 computationally-derived smoothing penalty that aims to avoid under-/over-fitting. This  
116 has an advantage over, for example, polynomial regression, as the analyst only needs to  
117 set an upper bound on non-linearity, rather than specifically determine the degree of non-  
118 linearity in advance. However, these methods are unable to incorporate a random effects  
119 structure into the model, which leads to anti-conservative estimates due to the fact that,  
120 for example, repeated productions from an individual speaker do not represent independent  
121 observations. One alternative is to use linear mixed-effects models with random intercepts  
122 and slopes (Stuart-Smith *et al.*, 2015). These models adequately account for the kinds  
123 of variability mentioned previously, but can only model linear trends in the data and are  
124 therefore inappropriate for modelling non-linearities.

125 Generalized Additive Mixed-Models (GAMMs) are an ideal solution to the above prob-  
 126 lems (Wood 2017; see Sós-kuthy 2017; Wieling 2018 for excellent tutorials applying GAMMs  
 127 to phonetic data). Similar to SS-ANOVA or Generalized Additive Modelling, GAMMs pro-  
 128 vide a data-driven method for quantifying non-linear trends, but they also allow for the  
 129 inclusion of *random smooths*, which can capture group or individual variation in non-linear  
 130 effects. This is similar to the use of random intercepts and slopes in a linear mixed-effects  
 131 model, but instead of only the height and slope being allowed to vary, random smooths per-  
 132 mit modelling of non-linearities in the relationship between predictor and outcome variables.  
 133 This has the benefit of more comprehensively capturing dependencies between adjacent data  
 134 points and allows us to better model variance in the data.

### 135 C. Hypotheses

136 In this study we compare the production of laterals and their surrounding vowels in  
 137 Liverpool and Manchester English, focusing on (i) lateral and vowel targets; (ii) time-varying  
 138 formant dynamics across the lateral and adjacent vowels. In light of the research reviewed  
 139 above, we make the following predictions with respect to our study:

140 H1. Initial laterals will have higher F2–F1 and lower F3–F2 than final laterals.

141 H2. Liverpool non-final laterals will have higher F2–F1 and lower F3–F2 than Manchester  
 142 non-final laterals.

143 H3. Liverpool will have higher F2–F1 in medial trochaic V2 than Manchester.



144 H4. Liverpool and Manchester will differ in a non-linear fashion across non-final time-  
145 varying lateral and vowel intervals, due to the prediction that there will be bigger  
146 dialect differences in the laterals (H2) than in the surrounding vowels.

147 We do not predict specific dialect differences in any other surrounding vowels except for  
148 those specified in H3. We have no reason to predict sociophonetic gender differences, but we  
149 anticipate that female speakers may produce higher formant values across the board. As a  
150 consequence, we do not predict significant interactions between gender and either position  
151 or dialect.

## 152 II. METHODS

### 153 A. Sampling and data collection

154 Data were collected from 46 speakers. 24 speakers were from Liverpool (12 female, 12  
155 male) and 22 speakers were from Manchester (13 female, 9 male). All speakers were aged  
156 between 19–27 years old, were born in their respective cities, and had lived there until at  
157 least the age of 18.

158 All recordings were carried out in a sound attenuated booth in Lancaster University Pho-  
159 netics Lab using a Beyerdynamic Opus 55 headset microphone, preamplified and digitized  
160 using a Sound Devices USBPre2 audio interface, and recorded to a desktop computer at 44.1  
161 kHz with 16-bit quantization. Stimuli were presented using PsychoPy in standard English  
162 orthography. Thirteen target words were elicited in the carrier phrase ‘she said X’, where  
163 X was a word with a lateral in one of four positional contexts: word-initial (*lead, lad, Lord,*

164 *lute, like*); word-medial trochaic (monomorphemic) (*belly, Bally*); word-medial morpheme  
 165 boundary (*filing, stalling*); word-final (*peel, pal, Paul, pool*). Each word was produced once  
 166 by each speaker, except for *like*, which was produced twice by each speaker due to this word  
 167 being elicited for an additional planned analysis. There were 93 non-lateral words in the  
 168 same test block, which served as distractors and were the subject of another experiment. 18  
 169 tokens were discarded due to recording errors or mispronunciations, leaving a total of 626  
 170 tokens for analysis.

## 171 B. Data processing and acoustic analysis

172 The audio recordings were downsampled to 22.05 kHz and low-pass filtered at 11 kHz.  
 173 Two acoustic intervals were then labelled using Praat: (1) a steady-state period of the  
 174 lateral; (2) the entire lateral-vowel (initial tokens), vowel-lateral-vowel (medial tokens) or  
 175 vowel-lateral (final tokens) interval. The steady-state period of the lateral was defined as  
 176 a period during the lateral at which the F2 trajectory was steady or as close to steady as  
 177 could be achieved, representing an unambiguously lateral phase ([Carter and Local, 2007](#);  
 178 [Kirkham, 2017](#); [Nance, 2014](#)). Praat TextGrids were converted to EMU annotation files for  
 179 use with the EMU Speech Database Management System ([Winkelmann et al., 2017](#)).

180 We carried out formant estimation via Linear Predictive Coding using a 22-order auto-  
 181 correlation method ([Markel and Gray, 1976](#)). Resonance frequencies were obtained by root  
 182 solving of the filter polynomial and formants were classified using the Split Levinson Algo-  
 183 rithm ([Delsarte and Genin, 1986](#)). This procedure was implemented using the `wrassp::forest`  
 184 R function ([Bombien et al., 2016](#)) in order to interface with the EMU-webApp. LPC anal-

185 ysis was based on a 20 ms Hamming window with 5 ms window shift, which was applied  
 186 across the entire signal file. Visual inspection of formant trajectories for every token was  
 187 carried out using the EMU-webApp ([Winkelmann and Raess, 2014](#)) and formant trajectories  
 188 were hand-corrected when the values visibly diverged from the formants on the wideband  
 189 spectrogram.

190 We report measurements of F2–F1 as a proxy for clearness/darkness in laterals, with  
 191 lower values suggesting darker laterals ([Sproat and Fujimura, 1993](#)). In addition to this,  
 192 we report analyses of F3–F2 because darker laterals are more likely to have low F2 and  
 193 high F3 ([Recasens and Espinosa, 2005](#)), which means that we expect this measure to further  
 194 discriminate between positional variants and also potentially between dialects.

195 We anticipate that the acoustics of lateral and vowel targets will interact due to coartic-  
 196 ulation. Accordingly, in order to compare lateral and vowel targets, we also report F2–F1  
 197 and F3–F2 from an adjacent vowel. In the case of word-medial contexts, we specifically  
 198 analyse V1 in morpheme boundary words (e.g. *stalling*) and V2 in medial trochaic words  
 199 (e.g. *belly*), because this is where we expect dialect differences to be largest in each context  
 200 (see Section [IA](#)). We note that our use of formant ratios, such as F2–F1, provide some  
 201 degree of speaker normalization, but no further normalization such as *z*-scoring was applied  
 202 to the data. This is because we are not only interested in the relationship between positional  
 203 variants within each variety, but also in the absolute clearness/darkness of laterals between  
 204 varieties.

205 For the time-varying analysis, we extracted measurements at 11 equidistant points from  
 206 the onset to the offset of the interval containing the lateral and surrounding vowels in each

207 word. Time normalization assumes that phonetically similar events occur at proportionally  
208 similar times across tokens with different durations, which may not always be the case.  
209 This is magnified when normalizing across different contexts, such as lateral-vowel versus  
210 vowel-lateral-vowel. The latter issue is not relevant here as our GAMMs focus only on  
211 within-context dialect differences. In order to resolve the former issue, we fitted linear  
212 mixed-effects models to the duration of the interval encompassing the lateral and its adjacent  
213 vowels. The null model had interval duration as the outcome variable, with speaker and  
214 word random intercepts and by-speaker random slopes for position. The test model added  
215 a position\*dialect interaction to the null model. We found no significant difference between  
216 these two models ( $\chi^2(7) = 12.57, p = .083$ ). As a consequence, we discount the role of  
217 interval duration differences as a potential explanation for our findings.

### 218 C. Statistical analysis

219 Data and code for all analyses reported in this article are publicly available at: <https://osf.io/5u6ez/>.

221 For the lateral and vowel targets analysis, linear mixed-effects models were fitted to the  
222 F2–F1 and F3–F2 values extracted from the the midpoint of (i) the lateral steady-state  
223 interval; and (ii) the vowel adjacent to the lateral. Models were fitted to the data using the  
224 lme4 package in R (Bates *et al.*, 2015). The models had either F2–F1 or F3–F2 as the  
225 outcome variable, with fixed effects of dialect, gender and position, and interactions between  
226 dialect\*gender, position\*gender and position\*dialect. We included random intercepts for  
227 speaker and word, as well as by-speaker random slopes for the effect of position.

228 Significance testing was conducted using likelihood ratio tests to compare a full model to  
 229 a nested model that excluded the term being tested for significance. When interaction terms  
 230 are significant, we do not report  $p$ -values for the main effects that are part of the relevant  
 231 interaction, but refer the reader to accompanying figures and model summaries. In cases  
 232 where all interactions in a given model are non-significant at  $p > 0.3$ , we test the significance  
 233 of main effects by comparing a model containing only main effects against a series of nested  
 234 models that each exclude the main effect of interest (Aikin and West, 1991; Harrell, 2015).

235 The time-varying analysis uses Generalized Additive Mixed-Models (Wood, 2017). For-  
 236 mant values were sampled at eleven equidistant points between the beginning and end of  
 237 the entire lateral and vowel sequence and separate GAMMs were fitted to the time-varying  
 238 F2–F1 and F3–F2 data at each position using the `mgcv::bam` function in R (Wood, 2017).  
 239 Predictor variables included a parametric term of dialect and smooth terms of normalised  
 240 time and a normalised time-by-dialect interaction. In order to improve statistical power and  
 241 model simplicity, the GAMMs exclude gender as a predictor, so all model estimates are de-  
 242 rived from collapsing over gender groups. We also fitted random smooths of time-by-speaker  
 243 and time-by-word. We tested the significance of dialect and the time-by-dialect smooth by  
 244 conducting model comparison as follows (Sóskuthy, 2017; Sóskuthy *et al.*, 2018):

- 245 1. We compare a full model (containing the dialect parametric term and time-by-dialect  
 246 smooth term) to a nested model excluding those terms, which allows us to test overall  
 247 effects of dialect and time-by-dialect on the trajectory.
- 248 2. If there is a significant difference in (1) then we specifically test for differences in the  
 249 shape of the trajectory by comparing the full model to a nested model excluding the

250 time-by-dialect smooth term. If this comparison is significant then we conclude that  
 251 there is a difference in shape of the two dialect’s trajectories. If not, then we conclude  
 252 that there is a difference only in the height of the two dialect’s trajectories.

253 All model comparison was conducted using the `itsadug::compareML` function (van Rij  
 254 *et al.*, 2017). Autocorrelation in trajectories was corrected using a first-order autoregressive  
 255 (AR1) model. We initially set the AR1 correlation parameter ( $\rho$ ) as the autocorrelation  
 256 value at lag 1 for each model, but changing this value to  $\rho = 0.3$  decreased autocorrelation  
 257 in the residuals to a greater degree for all models.

### 258 III. RESULTS

259 In this section we focus on positional, dialect and gender differences in lateral steady-state  
 260 and vowel midpoint formant values. The statistical analysis reports significance testing of  
 261 predictor variables via model comparison, followed by a more holistic interpretation of the  
 262 patterns via data visualization. Full summaries for all models in this section can be found  
 263 in Appendix A.

#### 264 A. Lateral steady-state

265 A linear mixed-effects regression model fitted to the lateral steady-state F2–F1 values  
 266 shows significant interactions between position\*dialect ( $\chi^2(3) = 9.06$ ,  $p = .028$ ) and di-  
 267 alect\*gender ( $\chi^2(1) = 5.40$ ,  $p = .020$ ), but no significant position\*gender interaction ( $\chi^2(3)$   
 268  $= 3.46$ ,  $p = .327$ ). As all main effects are also included as part of higher-level interactions,

269 we do not report their significance as they are not straightforwardly interpretable in the  
 270 presence of interactions. Figure 1 shows that there is robust contrast between initial and  
 271 final tokens for all groups, and that Liverpool typically has higher values than Manchester.  
 272 However, the significant position\*dialect and dialect\*gender interactions can be clearly seen  
 273 in the plots. For instance, Liverpool and Manchester females produce very similar final  
 274 /l/s, with Manchester females having slightly higher values (and thus a smaller initial~final  
 275 contrast). In contrast, Manchester males produce final /l/ with lower values than Liverpool  
 276 males.

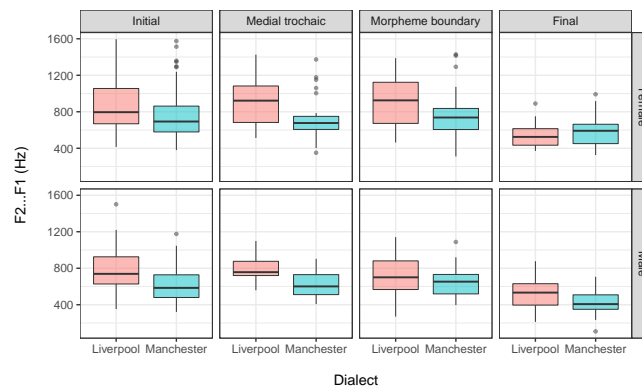


FIG. 1. F2–F1 values for /l/ steady-state. (Colour online).

277 The F3–F2 lateral steady-state model shows significant effects of position ( $\chi^2(3) = 14.07$ ,  
 278  $p = .003$ ), dialect ( $\chi^2(1) = 10.36$ ,  $p = .001$ ) and gender ( $\chi^2(1) = 11.29$ ,  $p < .001$ ), with no  
 279 significant interactions between any of these variables ( $p > .35$  for all interactions). Figure 2  
 280 shows that final tokens have higher values than non-final tokens, Manchester speakers have  
 281 higher values than Liverpool speakers, and female speakers have higher values than male  
 282 speakers. While the F3–F2 measurements largely mirror the F2–F1 values, there are some

283 differences, such as the existence of dialect differences in final /l/ for both female and male  
 284 speakers.

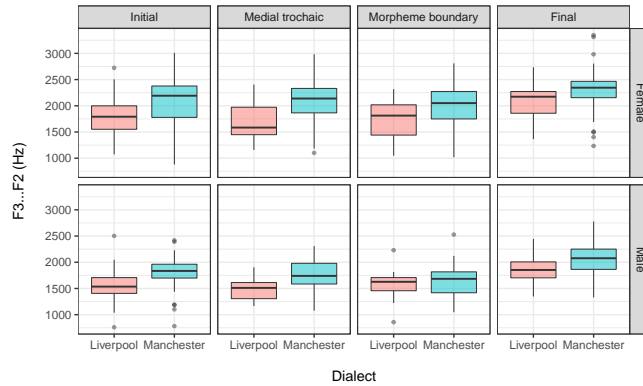


FIG. 2. F3–F2 values for /l/ steady-state. (Colour online).

## 285 B. Vowel midpoint

286 A linear mixed-effects regression model fitted to the vowel midpoint F2–F1 values  
 287 shows significant interactions between position\*gender ( $\chi^2(3) = 17.59, p < .001$ ) and po-  
 288 sition\*dialect ( $\chi^2(3) = 31.54, p < .001$ ), but not dialect\*gender ( $\chi^2(1) = 0.01, p = .924$ ).  
 289 As all main effects are also included as part of higher-level interactions, we do not report  
 290 their significance as they are not easily interpretable in the presence of interactions. Figure  
 291 3 shows that final tokens typically have lower values than non-initial tokens. Liverpool  
 292 typically has slightly higher values across all positions, except for morpheme boundary posi-  
 293 tion where dialect differences are very minor. It also appears that the magnitude of dialect  
 294 differences is greatest in the medial trochaic context, where Liverpool has higher values  
 295 than Manchester. Note that these vowel results are largely in the same direction as for the



296 lateral target analysis, but the difference between dialects is typically smaller in magnitude.  
 297 There are also instances in which the vowel distributions heavily overlap between dialects,  
 298 such as morpheme boundary and final contexts.

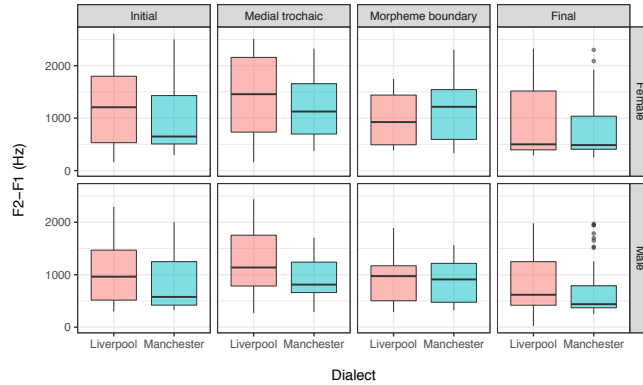


FIG. 3. F2–F1 values for vowel midpoint. (Colour online).

299 The F3–F2 model shows a significant interaction between position\*dialect ( $\chi^2(3) = 20.71$ ,  
 300  $p < .001$ ), but no significant dialect\*gender ( $\chi^2(1) = 0.42$ ,  $p = .518$ ) or position\*gender ( $\chi^2(3)$   
 301  $= 4.18$ ,  $p = .243$ ) interactions. Due to the significant position\*dialect interaction, we do  
 302 not report the significance of any main effects, but note that the very low  $t$ -value for the  
 303 gender main effect ( $\beta = -41.58$ ,  $SE = 49.77$ ,  $t = -0.84$ ) means that there is unlikely to be  
 304 meaningful gender differences in vowel F3–F2. Figure 4 shows that final tokens have higher  
 305 values than non-final tokens and Manchester has higher values than Liverpool in all contexts  
 306 except morpheme boundary position. Again, these results are largely similar to the lateral  
 307 target analysis, but the vowel dialect differences are consistently smaller in magnitude.

308 In summary, we observe relatively similar patterns across the lateral and vowel targets  
 309 analyses, with Liverpool generally showing higher F2–F1 and lower F3–F2 than Manch-

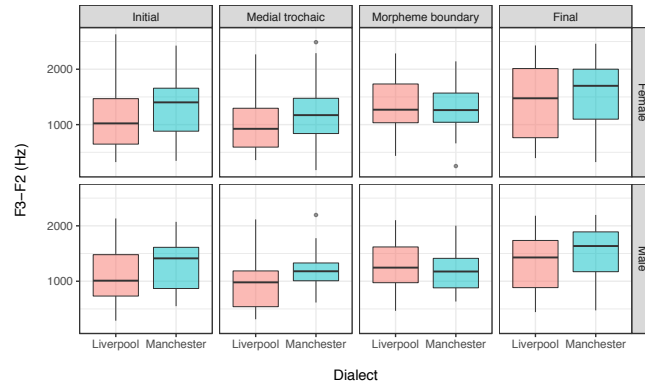


FIG. 4. F3–F2 values for vowel midpoint. (Colour online).

310 ester. However, while we see dialect differences across all positional contexts (except for  
 311 word-final /l/ amongst females), these differences are typically of a smaller magnitude in  
 312 the vowels. In some cases, such as morpheme boundary position, the dialects produce near-  
 313 identical vowel realizations. Overall, this suggests that there exists positional and dialect  
 314 variation in laterals, accompanied by a smaller degree of positional and dialect variation in  
 315 the surrounding vowels.

### 316 C. Time-varying analysis

317 In this section we report the GAMM analysis that models the effects of time and dialect  
 318 on formant values across the entire lateral and vowel(s) sequence at each position. We fit  
 319 separate models to each positional context and focus on dialect differences within contexts.  
 320 This is because (i) time-varying formants between positional contexts are unsurprisingly  
 321 different due to a different sequencing of the lateral and vowel phases between contexts; (ii)  
 322 time normalization across non-equivalent intervals (e.g. initial lateral-vowel versus medial  
 323 vowel-lateral-vowel) renders direct comparison of different positions somewhat problematic.

324 However, while we do not statistically test comparisons across positional contexts, they can  
 325 still be observed in the graphical model fits.

326 Table I shows the model comparisons used to test the significance of dialect and time-  
 327 by-dialect on F2–F1. For the initial tokens we find no overall effect of dialect. Medial  
 328 trochaic /l/ shows an overall effect of dialect, but further testing shows no significant effect  
 329 of shape, suggesting that the two dialects only differ in the height of the F2–F1 trajectory.  
 330 For morpheme boundary and final contexts we find no overall significant effect of dialect on  
 331 F2–F1.

332 The model fits for F2–F1 are visualized in Figure 5. In line with the model compar-  
 333 isons, word-medial trochaic tokens show a difference only in the height of the trajectory,  
 334 with Liverpool speakers showing higher F2–F1 across the lateral and vowel(s). Morpheme  
 335 boundary and final contexts also show an absence of non-linear differences, in addition to no  
 336 significant differences in the height of the trajectory. Word-final tokens in particular show  
 337 almost complete overlap between dialects, while word-initial tokens show only very small  
 338 dialect differences.. All trajectories only show a slight degree of non-linearity, so the data  
 339 also do not confirm our prediction of significant non-linear differences between dialects.

340 Table II shows the model comparisons used to test the significance of dialect and time-  
 341 by-dialect on F3–F2. For the initial and medial trochaic tokens we find an overall effect  
 342 of dialect, but further testing shows no significant effect of shape. This suggests that the  
 343 two dialects only differ in the height of the F3–F2 trajectory in these contexts. Morpheme  
 344 boundary context shows an overall effect of dialect, while specific testing of the time-by-

TABLE I. Model comparisons for F2–F1 GAMMs.

Comparison	$\chi^2$	$df$	$p(\chi^2)$
<b>Initial</b>			
Overall: dialect	2.70	3	.145
Shape: dialect	—	—	—
<b>Medial trochaic</b>			
Overall: dialect	4.62	3	.026
Shape: dialect	0.77	2	.463
<b>Morpheme boundary</b>			
Overall: dialect	2.92	3	.120
Shape: dialect	—	—	—
<b>Final</b>			
Overall: dialect	2.15	3	.231
Shape: dialect	—	—	—

345 dialect smooth term also shows a significant effect, suggesting significant dialect differences  
 346 in the shape of the trajectory. For the word-final tokens we find no overall effect of dialect.

347 The model fits for F3–F2 are visualized in Figure 6. The patterns for initial and medial  
 348 trochaic tokens show differences only in height rather than shape, with little-to-no overlap

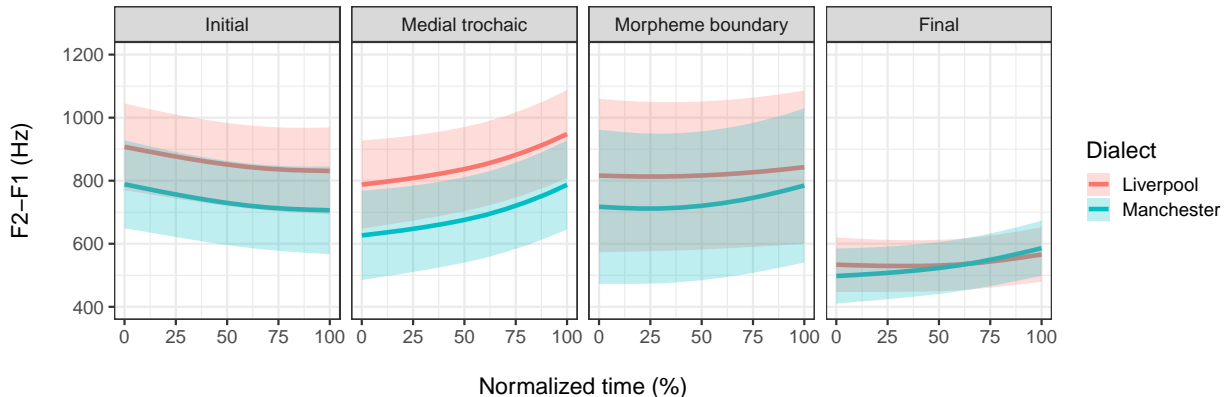


FIG. 5. Generalized Additive Mixed Model fits of the effects of normalized time-by-dialect on  $F2-F1$  (Hz) at each positional context. Each panel shows the full model fit for that positional context with a mean smooth and 95% confidence interval for each dialect. (Colour online).

349 in confidence intervals. Word-final position shows a small difference in height, but this  
 350 difference was not significant according to the model comparison. The morpheme boundary  
 351 context is the only example of a non-linear significant difference between dialects in our  
 352 time-varying data. While the differences in the overall height of the trajectory are smaller  
 353 than the other contexts, the Manchester group shows a more non-linear trajectory for these  
 354 tokens, with  $F3-F2$  showing the biggest dialect differences around the interval midpoint and  
 355 becoming most similar over the latter 50% of the V1-lateral-V2 interval. Our lateral and  
 356 vowel targets analysis found no significant dialect differences in the morpheme boundary V1,  
 357 while the GAMMs here show even fewer differences in V2 for the same context. Note that,  
 358 despite the lack of overall non-linear *differences* between dialects, there is a visibly greater  
 359 degree of non-linearity in the  $F3-F2$  trajectories when compared with  $F2-F1$ .

TABLE II. Model comparisons for F3–F2 GAMMs.

Comparison	$\chi^2$	$df$	$p(\chi^2)$
<b>Initial</b>			
Overall: dialect	5.62	3	.011
Shape: dialect	0.16	2	.849
<b>Medial trochaic</b>			
Overall: dialect	6.68	3	.004
Shape: dialect	0.93	2	.395
<b>Morpheme boundary</b>			
Overall: dialect	6.80	3	.004
Shape: dialect	4.52	2	.011
<b>Final</b>			
Overall: dialect	2.93	3	.119
Shape: dialect	—	—	—

#### 360 D. Summary of results

361 In summary, Liverpool speakers generally produce higher F2–F1 and lower F3–F2 than  
362 Manchester speakers in non-final /l/ contexts and in the adjacent vowels. In final /l/,  
363 Manchester males produce darker /l/s than Liverpool males, whereas female speakers pro-

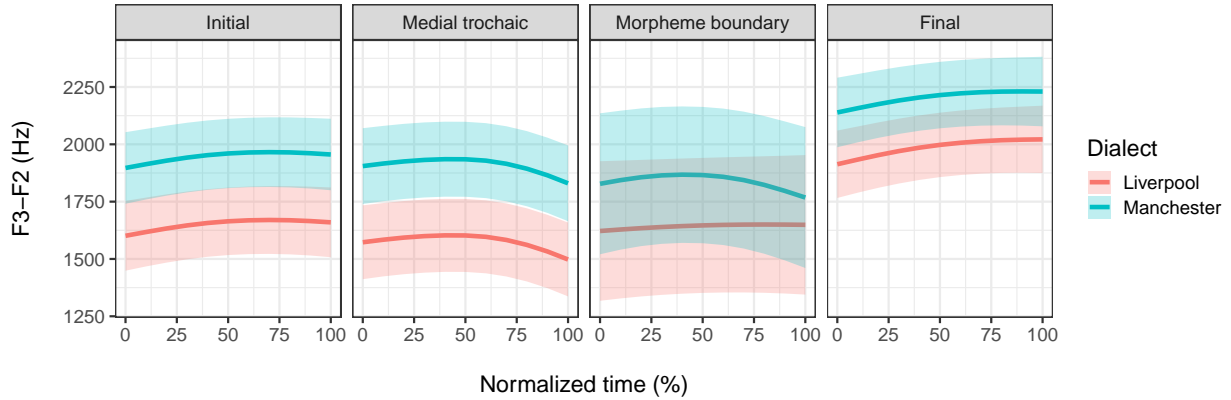


FIG. 6. Generalized Additive Mixed Model fits of the effects of normalized time-by-dialect on F3–F2 (Hz) at each positional context. Each panel shows the full model fit for that positional context with a mean smooth and 95% confidence interval for each dialect. (Colour online).

364 duce roughly similar F2–F1 values in this context. All groups produce contrast between  
 365 initial and final /l/ to some extent, although this is largest in Liverpool speakers and smallest  
 366 in Manchester females. The time-varying results collapsed the data across gender groups, so  
 367 we only observed dialect differences in this analysis. Accordingly, the GAMMs show global  
 368 differences in the height of the trajectory in F2–F1 for medial trochaic /l/, and in F3–F2  
 369 for all non-final contexts. However, the morpheme boundary F3–F2 model shows significant  
 370 non-linear differences, which are largest in the first 50% of the interval (roughly equivalent  
 371 to V1 plus lateral) and smallest during V2. In the following section, we discuss these results  
 372 with respect to our hypotheses and illuminate their broader significance.

373 **IV. DISCUSSION**374 **A. Time-varying formant patterns**

375 One of the major aims of our study was to offer a conceptual comparison between an  
 376 analysis of the lateral/vowel targets and an analysis of the time-varying lateral and vowel  
 377 formants. We find evidence of global F2–F1 and F3–F2 differences across the lateral and  
 378 vowel in medial trochaic contexts, and for F3–F2 in all non-final contexts. Surprisingly, the  
 379 only non-linear difference between dialects is in F3–F2 for morpheme boundary sequences.  
 380 Here we see the biggest difference in the middle of sequence (roughly representing the /l/) and  
 381 the smallest at the end of the sequence (roughly representing V2). This was not predicted;  
 382 in fact, we actually predicted that we would find non-linear differences in all contexts (H4),  
 383 with the magnitude of non-linearity largest in medial trochaic context (H3).

384 The non-linear difference in morpheme boundary context potentially represents the fact  
 385 that the two dialects differ in the lateral but not V2. This stands in contrast to medial  
 386 trochaic tokens, where we predicted and found differences in V2 (H3). A potential explana-  
 387 tion for this could lie in the morphological conditioning of /l/ and its subsequent influence  
 388 on the adjacent vowel. Medial trochaic contexts potentially allow for clearer realizations  
 389 (Hayes, 2000; Lee-Kim *et al.*, 2013; Sproat and Fujimura, 1993) and, therefore, arguably  
 390 greater potential for dialect variation. This may explain why we also see larger dialect dif-  
 391 ferences in medial trochaic vowels, while Figures 3 and 4 show little-to-no dialect differences  
 392 in morpheme boundary V1. Under this view, the medial trochaic vowel differences would be



393 a coarticulatory consequence of dialect differences in /l/, while the lack of such differences in  
 394 morpheme boundary vowels are due to the smaller dialect differences in /l/ in this context.

395 We believe that a more convincing explanation for these patterns is the likelihood of  
 396 robust dialect variation in medial trochaic vowels. Medial trochaic V2 was always what  
 397 Wells (1982) terms the HAPPY vowel, which is well-known to vary between dialects of British  
 398 English. In the south of England, this vowel is undergoing change from [ɪ] to [i] (Fabricius,  
 399 2002; Harrington, 2006), whereas in many northern varieties there are a range of backed  
 400 and centralized realizations, including [ɛ̃] (Hughes *et al.*, 2005; Kirkham, 2015). Manchester  
 401 English in particular is stereotyped for its centralised production of this vowel, which is  
 402 prevalent in working-class speakers (Baranowski and Turton, 2015). There is little prior data  
 403 on this vowel in Liverpool English, but the acoustic evidence in this study suggests that it is  
 404 produced with higher F2–F1 values, which would place it closer to [ɪ] and [i]. It is likely that  
 405 the coarticulatory relationship between clearer /l/s and higher-fronter vowels, and between  
 406 darker /l/s and lower-backer vowels, is magnified when both segments co-occur. Indeed, this  
 407 explanation has been pursued in previous work in which there are known differences in the  
 408 quality of this vowel between dialects (Kirkham, 2017) and this proposal may explain why  
 409 dialect differences tend to be largest for both the lateral and the adjacent vowel in medial  
 410 trochaic context.

411 Unsurprisingly, it is difficult to conclude whether the dialect differences we see here are a  
 412 consequence of the lateral (which then exerts coarticulatory influence on the vowel) or the  
 413 vowel (which then exerts coarticulatory influence on the lateral). In practice, the lateral  
 414 and its adjacent vowels appear to vary in tandem in some instances, although the targets

415 analysis suggests that the magnitude of the dialect difference at the lateral steady-state is  
 416 larger than at the vowel midpoint. Despite this, we did not find the predicted non-linear  
 417 time-varying differences at medial trochaic position in our GAMM analysis. One reason for  
 418 this could be that speaker and word level variance in the time-varying patterns is too large  
 419 to support significant non-linear differences between dialects. Indeed, this could suggest  
 420 that there is greater within-dialect variability in cross-segmental formant dynamics than in  
 421 segmental targets, which could lend support to the view that segmental targets are a more  
 422 prominent goal than cross-segmental dynamics. A more comprehensive investigation into  
 423 the relationship between segmental targets and time-varying acoustics is required in order  
 424 to address this issue further.

## 425 **B. English lateral typology**

426 Our static and time-varying analyses both find that Liverpool non-final /l/s typically  
 427 have higher F2–F1 and lower F3–F2 values than Manchester /l/s, which supports our  
 428 predictions (H2). Based on previous work on the relationship between acoustic measures  
 429 and impressionistic description ([Kelly and Local, 1989](#); [Recasens, 2012](#)), this suggests that  
 430 Liverpool has clearer realizations of /l/. However, while these results are predicted by the  
 431 literature and clearly evident in the data, it is important to note that these differences may be  
 432 comparably small when placed in context with other British English dialects. For example,  
 433 [Kirkham \(2017\)](#) reports data from Sheffield Asian (Punjabi-influenced) speakers producing  
 434 the same or very similar words as in the present study and reports mean F2–F1 values in  
 435 initial /l/ of 1679 Hz for male speakers and 1599 Hz for female speakers. The comparison is

436 somewhat hindered by the age difference between samples (13–14 in [Kirkham 2017](#); 19–27  
 437 in the present study). However, with this caveat in mind, the highest F2–F1 value for a  
 438 Liverpool female speaker producing initial /l/ is 1595 Hz, with most tokens around or below  
 439 1000 Hz. Therefore, in comparison to Sheffield Asian English – a variety with unusually clear  
 440 /l/s – Liverpool is probably best considered an ‘intermediate’ /l/ variety. This is in line with  
 441 previous impressionistic reports ([Knowles, 1973](#); [Wells, 1982](#)), as well as the instrumental  
 442 evidence available on Liverpool English ([Turton, 2014](#)).

443 Another salient aspect of /l/ variation is the implementation of positional contrast. Un-  
 444 surprisingly, initial laterals have higher F2–F1 and lower F3–F2 than final laterals (thus  
 445 confirming H1), with little evidence that word-medial laterals are significantly different from  
 446 initial laterals. However, we find that the initial~final contrast appears to be larger in Liver-  
 447 pool than in Manchester. This may reflect larger differences in the production of initial /l/s  
 448 in the two dialects, which we see in the absence of significant time-varying F2–F1 differ-  
 449 ences across the entire vowel-lateral interval in final position. We note that while positional  
 450 contrast in dark /l/ varieties of English, such as Manchester, is widely attested ([Carter and](#)  
 451 [Local, 2007](#); [Turton, 2014](#)), the production of initial~final contrast is not inevitable. For  
 452 example, previous work finds that some dark /l/ dialects of Catalan ([Recasens and Espinosa,](#)  
 453 [2005](#)) and English ([Kirkham, 2017](#)) do not show such positional variants.

454 To this end, one unexpected difference is gender variation in the initial~final contrast.  
 455 While Manchester males show lower F2–F1 than Liverpool males in initial and final po-  
 456 sition, Manchester females have similar or slightly higher values than Liverpool females in  
 457 final position. Individual-level data show that Manchester females are more variable in the

458 implementation of the initial~final contrast, with some speakers producing a small or no  
459 difference between positions. The size of these effects is relatively small and we did not  
460 predict their existence, so we do not wish to attach too much weight to them. However, in  
461 terms of possible explanations, [Turton \(2014\)](#) finds that working-class Manchester speak-  
462 ers may not produce an initial~final contrast in laterals, whereas middle-class speakers do.  
463 We did not collect information on the socioeconomic background of our participants, but  
464 it could be the case that some of the Manchester female speakers in our study are from  
465 more working-class backgrounds, which may interact with variation in the production of  
466 the initial~final contrast. Establishing the robustness of such effects motivates a need for  
467 tighter control over social stratification in experimental phonetic studies.

## 468 V. CONCLUSIONS

469 In this article we reported acoustic data on laterals, vowels and their time-varying formant  
470 dynamics in two major dialects of British English. We find that Liverpool generally has  
471 clearer non-final /l/s than Manchester. However, we propose that Liverpool English is best  
472 considered an ‘intermediate’ variety that lies towards the middle of the clear-dark continuum  
473 in English dialects. Our comparison of steady-state and time-varying results shows that the  
474 two analyses generally agree with each other, but the time-varying analysis further highlights  
475 the strong coarticulatory interactions between laterals and vowels in each dialect. This  
476 analysis also demonstrates that GAMMs are a versatile tool for modelling formant dynamics  
477 across multi-segmental sequences. In conclusion, analysing formant dynamics reveals that  
478 making strong claims about independent lateral and vowel targets should be approached with

479 caution, and future research into segmental targets and time-varying spectral information  
480 should seek to further address the specific nature of their relationship.

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#### 487 **APPENDIX A: LMER MODEL SUMMARIES**

488 For all models, baseline variables are Dialect = Liverpool, Position = Initial, Gender =  
489 Female. Random effects in each model include word and speaker random intercepts and  
490 by-speaker random slopes for the effect of position.

TABLE III. Lateral steady-state: F2–F1.

Variable	$\beta$	$SE$	$t$	$p(\chi^2)$
<b>Intercept</b>	883.21	64.38	13.72	—
<b>Dialect</b>				—
Manchester	-76.60	53.34	-1.44	
<b>Position</b>				—
Medial trochaic	-19.20	96.02	-0.20	
Morpheme boundary	-7.93	95.13	-0.08	
Final	-341.53	81.30	-4.20	
<b>Gender</b>				—
Male	-68.98	53.82	-1.28	
<b>Dialect x gender</b>				.020
Manchester:Male	-120.13	48.16	-2.50	
<b>Position x gender</b>				.327
Medial trochaic:Male	27.74	40.85	0.68	
Morph. boundary:Male	-35.09	38.38	-0.91	
Final:Male	39.27	44.80	0.88	
<b>Position x dialect</b>				.028
Medial trochaic:Manchester	-45.31	40.66	-1.11	
Morph. boundary:Manchester	22.21	38.20	0.58	

TABLE IV. Lateral steady-state: F3–F2.

Variable	$\beta$	$SE$	$t$	$p(\chi^2)$
<b>Intercept</b>	1793.50	85.25	21.04	—
<b>Dialect</b>				.001
Manchester	261.67	99.20	2.64	
<b>Position</b>				.003
Medial trochaic	−56.67	96.52	−0.59	
Morpheme boundary	−40.14	95.91	−0.42	
Final	335.54	94.17	3.56	
<b>Gender</b>				< .001
Male	−254.55	100.92	−2.52	
<b>Dialect x gender</b>				.872
Manchester:Male	22.42	137.28	0.16	
<b>Position x gender</b>				.881
Medial trochaic:Male	−23.99	62.18	−0.39	
Morph. boundary:Male	34.79	61.89	0.56	
Final:Male	−6.00	80.27	−0.08	
<b>Dialect x position</b>				.354
Medial trochaic:Manchester	37.72	61.89	0.61	
Morph. boundary:Manchester	−77.26	61.57	−1.26	

TABLE V. Vowel midpoint: F2–F1.

Variable	$\beta$	$SE$	$t$	$p(\chi^2)$
<b>Intercept</b>	1253.78	216.56	5.79	—
<b>Dialect</b>				—
Manchester	−227.71	42.02	−5.42	
<b>Position</b>				—
Medial trochaic	926.46	407.66	2.27	
Morpheme boundary	−618.89	404.45	−1.53	
Final	−357.80	324.24	−1.10	
<b>Gender</b>				—
Male	−175.76	42.50	−4.14	
<b>Dialect x gender</b>				.924
Manchester:Male	−4.62	47.25	−0.10	
<b>Position x gender</b>				< .001
Medial trochaic:Male	−247.55	90.23	−2.74	
Morph. boundary:Male	143.49	68.19	2.10	
Final:Male	104.43	53.20	1.96	
<b>Position x dialect</b>				< .001
Medial trochaic:Manchester	−298.23	89.85	−3.32	
Morph. boundary:Manchester	268.38	67.86	3.96	



TABLE VI. Vowel midpoint: F3–F2.

Variable	$\beta$	$SE$	$t$	$p(\chi^2)$
<b>Intercept</b>	1146.84	197.90	5.80	—
<b>Dialect</b>				—
Manchester	166.07	49.03	3.39	
<b>Position</b>				—
Medial trochaic	−577.74	368.40	−1.57	
Morpheme boundary	455.20	367.33	1.24	
Final	300.99	294.62	1.02	
<b>Gender</b>				—
Male	−41.58	49.77	−0.84	
<b>Dialect x gender</b>				.518
Manchester:Male	41.97	63.70	0.66	
<b>Position x gender</b>				.243
Medial trochaic:Male	63.67	69.54	0.92	
Morph. boundary:Male	−98.14	62.07	−1.58	
Final:Male	−79.15	49.48	−1.60	
<b>Position x dialect</b>				< .001
Medial trochaic:Manchester	159.38	69.22	2.30	
Morph. boundary:Manchester	−266.24	61.77	−4.31	

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