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Research Article

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Variation in the formant of ethno-regional varieties in Nigerian English vowels

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Abstract: Unlike previous studies on Nigerian English (NigE) that consistently report mid-point analysis to describe NigE vowels, this study employs spectral changes because it reveals inherent changes, which characterize vowel formants over time. Earlier research, for example, claims that a sub-variety of NigE (e.g., Western Nigerian English – WNigE) does not have phonetic differences between tense and lax. This study, therefore, examines the nature of the dynamic spectral changes of WNigE high and low lexical sets (such as TRAP/BATH, KIT/FLEECE, and FOOT/GOOSE) produced by 75 WNigE speakers who are born and raised, and currently reside in the west, east, and north of Nigeria. Two- and nine-point vowel measurements were employed to estimate the formant dynamics with $F1$ and $F2$ vector length, trajectory length (TL), formant velocity, and formant trajectories with the Generalized Additive Mixed Model. The results show the importance of examining the WNigE vowel using nine-point measurements rather than the two-point or mid-point. Our results reveal that WNigE vowels have phonetic differences, evidenced in formant trajectories. Social and linguistic factors also affect WNigE vowel production. Regions influence the TL of vowels, with WNigE speakers in the north and west regions showing longer TL than those in the east.

Keywords: Nigerian English vowels, ethno-regional variation, formant dynamics, social and linguistic factors

1 Background

Nigerian English (NigE) has long been understudied in terms of its acoustic properties, especially variation in vowel production. The limited available research often suffers from methodological shortcomings, such as over-reliance on vowel mid-point measurements and focusing on vowel duration to determine tense-lax distinctions (Atanda et al. 2017). The method neglects formant trajectories, transitions, and change, which provide insights into vowel identity and variation for regional differences (Ata 2015, Isiaka 2019, Bello et al. 2020). The present study employs several-point vowel measurement to estimate formant tracking, trajectory length (TL), formant velocity (FV), and other dynamic variables to describe linguistic and social factors that affect NigE vowel realizations.

Similarly, the earlier approach to NigE vowels compares NigE with Received Pronunciation (RP) (Simo Bobda 2000, Oladipupo 2014, Oladipupo and Akinola 2022, Olaniyi 2023, Olajide and Olaniyi 2013). Many of these studies framed variations (in NigE) from RP as ‘errors’ or ‘deviations’ (Tiffen 1974, Ajani 2007, Jamakovic and Fuchs 2019), and they conceptualized RP as a normative standard or baseline for NigE vowel realization. Though some of them (Jamakovic and Fuchs 2019) do not use the term ‘normative standard or baseline,’ but the rationale to compare how NigE speakers produce vowels with how RP vowels are realized is not far from recognizing RP as the baseline for NigE.

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Particularly, Tiffen's work was modeled, using RP as the normative standard to describe the intelligibility of NigE segments. It is important to note that RP and NigE do not have the same or similar language ecology; therefore, there is no justification for such a comparison (Filppula et al. 2017, Low and Pakir 2018, Schneider 2016).

However, more recent studies on NigE vowels have shifted focus to comparing sub-varieties based on education (Varieties 1, 2, and 3) and region (east, north, south, and west) (Ugorji 2010, Taiwo 2012, Melefa 2019, Amoniyan 2023, 2025). This attempt helps to describe NigE and how the sub-varieties are similar or different from others (Mesthrie 2008). Since every sub-variety of NigE has a similar language ecology and belongs to a similar multilingual environment, the approach benefits the description of NigE vowels and the codification of the sub-varieties of NE (Akujobi and Umoh 2022). To add, there has not been any known study on NigE vowels that examines (particular) speakers of NigE who are born and reside in other regions that differ from their ancestral home. The current study examines Western NE (WNigE) speakers who are ethnically Yoruba and have Yoruba as their first language, born, raised, and currently residing in the western, eastern, and northern regions of Nigeria. The goal is to compare the vowel production of those in the east and north to their counterparts residing in the west.

Despite the importance of the newer approach (even with the earlier one), the method of vowel measurement has consistently been at a mid-point or steady point. This method estimates the vowel's formant frequencies at the mid-point, which explains the static nature/behavior of the vowel formant. However, the method neglects the rationale for spectral changes that occur during vowel production. In reality, vowel identity is shaped by the entire trajectory of formant movement from the onset to the offset of the vowel, regardless of whether the vowels are monophthongs or diphthongs (Kiefte and Kluender 2005, Fox and Jacewicz 2009, Kent and Vorperian 2018). Relying on static/mid-point vowel measurement to analyze vowels, as seen in earlier studies, obscures the complexities of how vowels are produced (or change over time), especially in NE, the variety that may exhibit intra- and inter-speaker variation by sub-varieties.

However, recent approaches for investigating vowels in other varieties of English, for example (Morrison 2013, Hillenbrand 2013, Fox and Jacewicz 2017), suggest that mid-point is insufficient to explain vowel identity. Instead, formant transitions, changes in formant frequencies over time, provide more detailed information about vowel characteristics. For instance, one promising framework for analyzing vowel variation in this study is vowel inherent spectral change (VISC), which posits that vowel identity is not static but dynamic, evolving throughout the vowel. Studies in other varieties of English such as American English (Fox and Jacewicz 2009, Hillenbrand 2013) have shown that several-point formant measurements, tracking formant frequencies at multiple time intervals during the vowel, reveal more about vowel identity than mid-point measurements alone. It is evident in the VISC description that formant frequencies change continuously from the onset to the offset of the vowel, and these changes phonetically differentiate vowels that would otherwise appear similar if only the mid-point were considered.

In this study, the VISC approach is explored to identify vector length (VL), TL, FV, and formant trajectories with generalized additive mixed model (GAMM) as methods of analyzing WNigE vowel dynamics. These methods are useful in analyzing vowel pairs that are commonly debated in NE, such as TRAP~BATH, KIT~FLEECE, and FOOT~GOOSE, where formant transitions can provide a clearer picture of vowel contrast than the mid-point. For example, it is 'only' Isiaka 2019 and Jowitt 2018, irrespective of the mid-point approach, that explains phonetic contrast in the vowels of the northern NE, while other studies report no evidence of phonetic differences in NigE vowels. The current study uses different VISC approaches (e.g., VL, TL, FV, GAMM) to explain whether there is a phonetic difference in the WNigE vowels.

By focusing on these dynamic measures, this study provides factors (social and linguistic) that can determine formant trajectories in WNigE. More so, the approach of this study differs from the prescriptive comparisons with RP that have dominated the literature on NigE, instead recognizing NigE as an independent variety with its own distinct phonetic and phonological characteristics. The findings of this study will highlight the importance of region, geographical location, and the dominant language of the immediate environment on the vowels of NigE.

1.1 Ecology of NigE

Nigeria is known for its diversity and dynamic interplay between indigenous languages and sociocultural factors shaped by regions. Nigeria is home to over 500 languages, and the distribution of these languages reflects the country's complex sociolinguistic landscape, shaped by geography, migration, and historical interactions (Lewis et al. 2009). Each region has a dominant language(s) within its ecology. For example, in the west, Yoruba is spoken predominantly, but also by westerners who reside in the east, north, and other parts of the country due to migration and inter-ethnic business, marriages, and education (Adewale 2005, Olajide 2014, Amrevurayire and Ojeh 2016, Ajani and Fakunle 2018). The immediate regions where westerners live contribute to their vowel variations. For this study, the speakers' region (as a place of birth and residence) is expected to play an important role in shaping how WNigE vowels are realized. In regions such as the north and east of Nigeria, where Yoruba speakers coexist with speakers of Hausa (in the north) and Igbo (in the east), WNigE vowel spaces may exhibit adaptation influenced by dominant languages in the north and east (Puig-Mayenco et al. 2018). For instance, the formant trajectories might change differently between the westerners who are born, raised, and residing in the west and the westerners in the northern and eastern regions with dominant other languages (e.g., Hausa and Igbo) (Nearey 2013, Feimster Holt and Ellis 2018).

1.2 Present direction

Our study describes the variance in formants characterized by high-low WNigE vowels (TRAP~BATH, KIT~FLEECE, and FOOT~GOOSE) produced by WNigE speakers in the east, north, and west regions of Nigeria. The dynamic variations in the formants $F1$ and $F2$ were examined using VL, TL, FV, and GAMM. Content words were included in both citation and passage reading. This study investigates whether employing two- or three-point measures yields differing results in formant transitions and whether these measures better describe the variability of WNigE high-low vowels. Additionally, the potential of VL, TL, FV, and GAMM is explored in estimating the extent of formant changes over time.

A key focus of this study is analyzing WNigE vowels in both passage and word list styles. These vowels were selected for two main reasons. First, they are among the most debated monophthongs regarding whether vowel contrast exists in WNigE. According to Jowitt 2018, Oladipupo and Akinola 2022, these vowels do not exhibit phonetic contrast. However, they are widely used across WNigE, making them ideal for cross-dialectal comparisons. Examining these vowels provides insight into how WNigE speakers may differ from speakers in other regions, particularly in terms of accent variation and indigenous language influences. Second, these vowels cover a broad spectrum of the vowel space offering a comprehensive basis for phonetic analysis.

The selection of these vowel pairs is further motivated by their phonetic status within NigE sub-varieties, as identified in previous studies (Isiaka 2019, Jowitt 2018), which suggest that regional variation plays a significant role in vowel restructuring. Rather than comparing these contrasts to RP, this study focuses on how they emerge within NigE itself. The choice to prioritize vowel height ($F1$) over frontness/backness ($F2$) is based on VISC research (Fox and Jacewicz 2009, Hillenbrand 2013), which indicates that $F1$ transitions are more dynamic and informative for vowel contrast. Specifically, Jowitt 2018 has observed vowel height distinctions in NigE, making $F1$ an important acoustic parameter for this study. Given that this study employs formant trajectory analysis, vowel height ($F1$) provides a more robust dimension for capturing regional and socio-linguistic variation in NigE vowels.

Analyzing these vowels in both word list and passage reading provides insight into both the stability and variability of vowel production in WNigE speakers. Word list reading tends to overestimate phonetic distinctions, whereas passage reading reflects more naturalistic speech patterns, allowing for a comprehensive examination of vowel variation (Heinrich and Smakman 2015). Examining the same vowels across these two reading styles provide insights into whether sociolinguistic and linguistic factors contribute to differences in vowel production.

1.3 Research hypotheses

Hypothesis 1

Vowels TRAP~BATH, KIT~FLEECE, and FOOT~GOOSE produced by WNigE speakers from the west, north, and east exhibit significant differences in the amount and direction of spectral change, as measured by VL, TL, FV, and formant trajectories. These differences are expected to reflect through social and socio-biological factors.

Hypothesis 2

The reading style (word list items vs passage) influences the formant transitions of WNigE speakers' vowels TRAP~BATH, KIT~FLEECE, and FOOT~GOOSE, with word list expected to show more stable and distinct formant patterns than passage reading. This difference is hypothesized to be more pronounced/distinguished in vowels from WNigE speakers living in the west than those from the north and east.

Hypothesis 3

Several point formant measurements yield differing results in describing the vowel formant transitions of WNigE speakers' vowels TRAP~BATH, KIT~FLEECE, and FOOT~GOOSE (Wells 1982). Specifically, nine-point measures are hypothesized to provide a more detailed and better representation of the dynamic variability in formant changes, particularly in better capturing the formant shape, change, and direction with GAMM. This offers a better understanding of vowel identity and contrast in WNigE.

The predictions indicate that WNigE vowels vary based on the speakers' regions and linguistic styles. WNigE speakers from the north are expected to show greater $F1$ formant variability and higher $F1$ trajectories moving in the opposite direction with speakers from the west. For the second research question, previous studies (Fox and Jacewicz 2009, Jacewicz and Fox 2012) show that vowels in citation/word lists are more peripheral and exhibit greater spectral variation than vowels produced during passage reading. Consistent with these findings, vowels in word item lists are anticipated to display more stable formant movement than passage. Finally, addressing the third research question, three-point measurements are expected to capture linear, nonlinear, and curved formant trajectories more effectively than two-point measures.

2 Methods

2.1 Participants

Seventy-five (75) WNigE speakers participated in the study: 25 each from east, north, and west (age range = 18–42 years). These speakers have a minimum of university education to satisfy the educated variety of WNigE (Udofot 2004). The speakers resided specifically in Ogbomoso, Oyo state (west), Nsukka, Enugu state (east), and Jos, Plateau state (north) and they were operationalized as place of birth (POB). Ogbomoso in Oyo state is Yoruba's ancestral home in western Nigeria. Nsukka, Enugu state, is home to Igbo speakers, and Plateau is home to Hausa speakers; however, there are westerners domiciled in Hausa and Igbo communities. In addition, in our study, the westerners in the east speak the eastern dominant language (Igbo) simultaneously with Yoruba, and those in the north are fluent in Yoruba and Hausa. We expect to see the effect of Igbo and Hausa on vowel production to differentiate them from westerners who speak Yoruba and reside in Yoruba dominated environments. The metadata retrieved attests that WNigE speakers in the east and north use Yoruba, Hausa, and English; however, the use of these three different languages depends on context and the language that the hearers understand (Adegbija 2000). The case is analogous to WNigE speakers in the east. For the WNigE speakers in the west, they use Yoruba and English depending on the context and the language that the hearers speak. All the speakers can speak and write in Yoruba, though we did not test their proficiency; however, we spoke (central dialect of) Yoruba at different times during the data collection.

Also, as seen in the sociolinguistic questionnaire administered to all the participants during the reading task, the 75 WNigE speakers had comparable education, socioeconomic status, and birthplace (all born in three major regions of Nigeria). They were either degree or post-graduate holders with English as a lingua franca.

2.2 Speech materials and procedures

The data collection instrument consists of two sections: the first section contains a passage with 171 words, while the second section includes a 40-word item list. Both passage and citation have TRAP~BATH, KIT~FLEECE, and FOOT~GOOSE in content words as target words. These target vowels have varied consonants: alveolar, dental, labial, palatal, velar, and labiodental in the preceding and following phonological environment. WNigE speakers in the three regions were individually recorded in a noise-minimized environment in Ogbomoso (west), Nsukka (east), and Jos (north). Geographically, the west is 663.42 km from the East and 456.36 km from the north, respectively (Natural Earth n.d.).

The speakers were recorded for the two tasks after securing their consent. First, they read the passage and then the word item lists. This approach does not make the speakers aware of the target words. Both tasks were presented to the participants in written form. Both the text and the audio files were forced-aligned automatically in WebMAUS and the alignment was manually adjusted where necessary in Praat (Boersma and Weenink 2030). After this stage, a trained degree holder in English was recruited to cross-check the adjustment, and the interrater reliability agreement was 90%. The 10% differences were resolved before the formant extraction. A modified Praat script by Riebold 2013 was used to extract $F1$, $F2$, and $F3$ at 10% intervals for nine points. A total of 3,375 tokens were extracted for the target (content) words. By regions, there were 1,141 tokens for WNigE speakers in the west, 1,065 tokens from the WNigE speakers in the north, and 1,169 for WNigE speakers from the east (Table 1).

Table 1: Social and linguistic factors by tokens (n = 3,375)

Category	Factor	Tokens
Vowels	BATH	412
	FLEECE	340
	FOOT	133
	GOOSE	1,034
	KIT	1,224
	TRAP	232
Gender	Male	1,461
	Female	1,875
	NA	39
POB	east	1,169
	north	1,065
	west	1,141
Education	Degree	2,709
	Postgraduate	520
	NA	146
Age	Teenager	731
	Young adults	2,586
	NA	58
Consonant sequence	CV	738
	CVC	2,520
	VC	117
Reading type	Passage	2,651
	Word list/citation	724

2.3 Vowel measurement

2.3.1 Vowel normalization

For formant trajectory changes, the frequency values of the first two formants ($F1 \times F2$) were extracted at nine points of vowel durations. Formants less than 20% vowel duration were excluded from the analysis to reduce the effects of formant transitions that characterized consonant neighboring (Kitikanan et al. 2022, Levy and Hanulíková 2022). The extracted values were converted to Bark metrics using (Traunmüller 1990) formula in R environment:

$$Z = [26.81f/(1960 + f)] = 0.53,$$

where Z represents the critical-band rate in Bark, while f refers to the raw frequency in Hertz (Traunmüller 1990). The scaling factor 26.81 is used to convert the frequency (f) into the critical-band rate (Z) measured in Bark units. The value 1,960, appearing in the denominator of the equation, is a frequency-dependent term that acts as an offset, facilitating the accurate conversion from frequency to the critical-band rate.

These parameters were derived from empirical research to define a mathematical model approximating human perception of frequency in terms of the critical-band rate in Bark units. This model provides a robust approximation of the psychoacoustic characteristics of human hearing. The adjustment factor of 0.53 serves to align the Bark scale with the equivalent rectangular bandwidth scale.

For each speaker, $F1 \times F2$ values in Bark were calculated for each vowel. These values were used to compute metrics such as VL, TL, FV, and formant trajectories.

2.3.2 VL

VL measures the extent of dynamic formant movement within a vowel. This method has been used to investigate formant variation in English vowels (Fox and Jacewicz 2009, Ferguson and Kewley-Port 2002) and to compare VISC differences between L2 and L1 English vowels (Jin and Liu 2013). Jin and Liu 2013 referred to VL as the 'Distance of VISC,' although the formula underlying these metrics remains identical. Longer VL values signify greater formant movement, with diphthongs and diphthongized vowels typically showing longer vectors than monophthongs due to greater formant variability. VL is computed as the distance (in Barks) between 25 and 75% of the vowel's duration within the $F1 \times F2$ vowel space

$$\mathrm{VL} = \sqrt{}(F1^{80\%} - F1^{20\%} + F2^{80\%} - F2^{20\%})^2,$$

where VL can be computed using either Barks (Ferguson and Kewley-Port 2002, Jin and Liu 2013) or Hertz (Fox and Jacewicz 2009); in this study, VL, TL, and FV were calculated in Barks.

2.3.3 TL

TL is the sum of the Euclidean distances (in Barks) between 20 and 80% points of the two vowel sections. While the original method in the study by Fox and Jacewicz 2009 employed five measurement time points (20, 35, 50, 70, and 80%), in this study, three temporal points (20, 50, and 80%) were used, as done in other studies (Romanelli and Vélez-Agudelo 2024). The length of each vowel section (VSL) was first calculated based on the following formula:

$$\mathrm{VSL}^{20-50\%} = \sqrt{}(F1^{20\%} - F1^{50\%} + F2^{20\%} - F2^{50\%})^2,$$

$$\mathrm{VSL}^{50-80\%} = \sqrt{}(F1^{50\%} - F1^{80\%} + F2^{50\%} - F2^{20\%})^2.$$

Then, the total length of TL was measured by adding the two vowel sections:

$$\mathrm{TL} = \mathrm{VSL}^{20-50\%} + \mathrm{VSL}^{50-80\%}.$$

A longer TL corresponds to much change in formant frequency values and more formant movement. TL is important for determining the formant movement observed in tense-lax vowels and vowels with curved (U-shaped) formant trajectories (Fox and Jacewicz 2009). TL has been used in many studies to assess cross-dialectal variation in the formant dynamics of English vowels (Hirata and Tsukada 2004, Story 2007, Fox and Jacewicz 2009, Yang and Fox 2013, Renwick and Stanley 2020).

2.3.4 FV

In this study, the FV metric of $F1 \times F2$ slope measure (in Bark/100 ms units) used to describe WNigE vowels across regions (Schwartz 2021) is employed. FV is computed independently for $F1$ and $F2$ formants within two distinct portions of the vowel: 20–50% and 50–80%. FV values within each portion are calculated as the difference in formant frequencies between two temporal points, divided by the duration between each of these points. The direction of formant change was assessed by including both positive and negative values. The implemented formula for each vowel portion is as follows:

$$\text{FV}F1\ \text{onglide} = (F1^{20\%} - F1^{50\%})/\text{Duration},$$

$$\text{FV}F1\ \text{offglide} = (F1^{50\%} - F1^{80\%})/\text{Duration},$$

$$\text{FV}F2\ \text{onglide} = (F2^{20\%} - F2^{50\%})/\text{Duration},$$

$$\text{FV}F2\ \text{offglide} = (F2^{50\%} - F2^{80\%})/\text{Duration}.$$

Larger FV values indicate greater formant change, while positive and negative values indicate a rise or drop in formant values. It is worth noting that, unlike Euclidean distance measures (such as VL and TL), FV considers vowel duration. Longer vowels provide more space for formant movement, so ignoring vowel duration may produce misleading results. Another thing to note is that VL and TL use absolute values, which are only positive values. In contrast, FV uses both positive and negative values because we want to capture how formant values rise and fall. This study focuses on specific predictions about the amount and direction of formant movement in each vowel segment, which will be tested using the FV metric. Separate analyses were conducted for $F1 \times F2$ using independent repeated-measures multivariate analysis of variances (MANOVAs). Formants are not comparable. In acoustic studies, it is common to analyze $F1$ and $F2$ separately by studying vowels (Divenyi 2009, Lammert and Narayanan 2015, Herrero De Haro 2021, Romanelli and Vélez-Agudelo 2024).

2.3.5 Statistical model for the study

This study employs a stepdown statistical approach to analyze formant variation in WNigE vowels, using VL, TL, FV, and formant trajectories as dependent variables. The independent variables include both social and linguistic factors. To examine the relationship between these factors, MANOVA and GAMM were used. MANOVA was applied to each of these: VL, TL, and FV, to assess overall group differences, while GAMM was employed to capture nonlinear spectral changes in formant trajectories over time. The stepdown modeling approach was implemented to determine the best-fitting statistical models for the dataset.

For VL, TL, and FV, the MANOVA model analyzed how formant dynamics vary across regions and reading styles. VL measures the extent of dynamic formant movement, with longer VL values indicating greater vowel instability. TL captures the total trajectory of formant movement, reflecting tense-lax vowel distinctions and regional variation in formant trajectories. FV, in contrast, measures the speed and direction of spectral change, incorporating both positive and negative values to track rising or falling formant movements. The combination of these three measures provides a comprehensive analysis of vowel spectral variation across social and linguistic factors.

For a more detailed analysis of formant trajectories, GAMM was employed. This approach allows for smooth, non-parametric modeling of vowel dynamics, making it appropriate for speech data. Unlike traditional linear models, GAMM does not assume a fixed relationship between time and formant values; instead, it fits adaptive smooth functions to track formant transitions over time. By integrating MANOVA and GAMM, this study accounts for both categorical and continuous phonetic variation, ensuring a robust statistical framework for analyzing vowel production in WNigE. All descriptive, visualization, and statistical analyses were performed with the software R version 4.4.0 (R Core Team 2020). Additional packages such as "tidyverse" version 2.0.0 (Wickham et al. 2019), "rstatix" version 0.7.2 (Kassambara 2023) and (M)ANOVA were used and their results were duly reported in the analysis and discussion.

To complement statistical significance testing, effect sizes were calculated to assess the magnitude of observed differences. For repeated-measures ANOVAs, eta squared (η^2) was computed to determine the proportion of variance in VL and TL attributable to each main effect and interaction. For pairwise comparisons between vowel categories (e.g., FLEECE vs KIT), Cohen's d was calculated to estimate standardized mean differences. Effect sizes were interpreted using established benchmarks (small = 0.01/0.20, medium = 0.06/0.50, large = 0.14/0.80 for η^2/d, respectively (Cohen 2013)), and all analyses were conducted in *R* using the *effectsize* package (Ben-Shachar et al. 2020).

3 Results

This section analyzes WNigE vowels (TRAP~BATH, KIT~FLEECE, and FOOT~GOOSE) across social (POB, gender), socio-biological (age), and linguistic (reading type, syllable sequence) factors by TL, FV, VL, and formant trajectories.

3.1 Data analysis and interpretation

Direction and amount of formant movement and direction of high-low vowels (TRAP~BATH, KIT~FLEECE, FOOT~GOOSE) of WNigE speakers across POB and reading styles were examined. Figure 1 compares the group

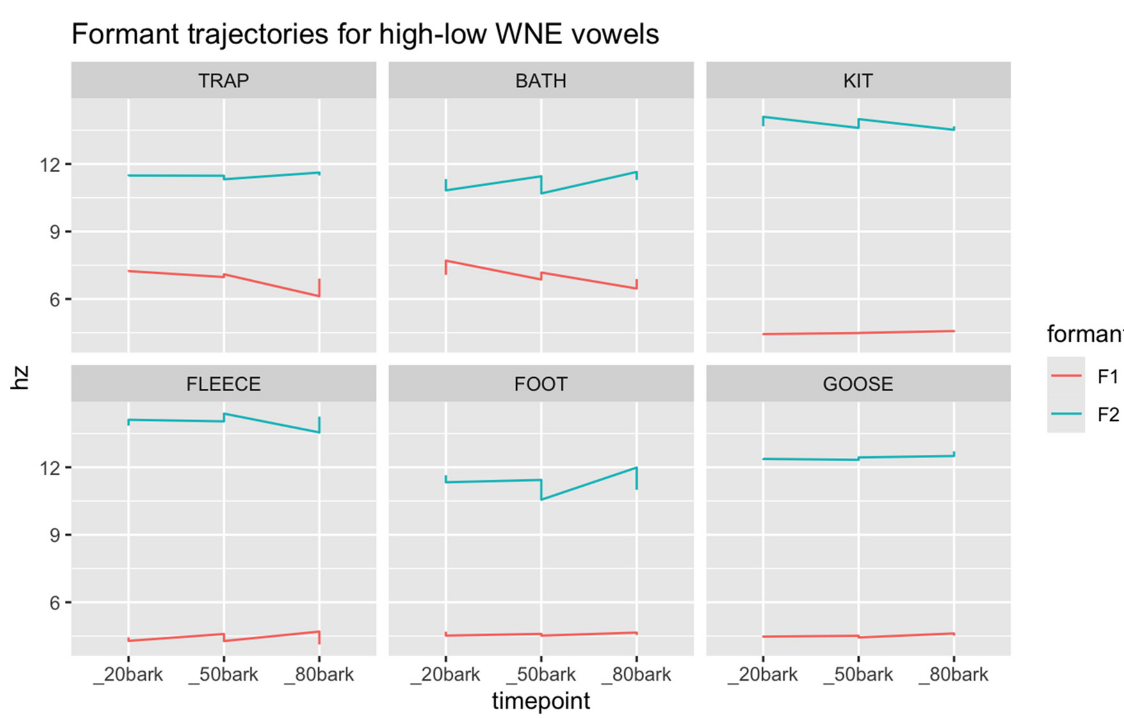

Figure 1: Bark normalized *F*1 × *F*2 values averaged across all participants for the TL, direction and elbow (straight vs elbowed) of WNigE high-low vowels across 20, 50, and 80% of vowel durations.

mean formant trajectories for high-low vowels for WNigE. Based on visual inspection, WNigE high-low vowels showed different formant movements. However, Figure 1 further reveals that the patterns of formant movement varied across the POB. Differences in formant direction and/or magnitude were observed among WNigE speakers, and the effect of POB contributed to their formant transitions, as shown in Figure 2. Figure 3 further reveals how the vowels varied across reading styles.

First, Figure 1 presents the formant trajectories for six vowels (TRAP, BATH, KIT, FLEECE, FOOT, and GOOSE) in WNigE across vowel duration. The first formant ($F1$) and the second formant ($F2$) are plotted on the y-axis, with the frequency in Hz indicated on the left and timepoints on the x-axis.

Observations in Figure 1:

TRAP: $F1$ shows a downward trend, indicating a decrease in formant level as the vowel progresses, while $F2$ remains relatively stable, suggesting a consistent tongue position in terms of height.

BATH: $F1$ shows a slight decrease over time, while $F2$ increases slightly, particularly at the 80% time point, reflecting a shift in tongue position toward the front of the mouth.

KIT: $F1$ is stable with a slight increase at the final timepoint, and $F2$ shows a slight decrease, showing a shift in the phonetic retraction.

FLEECE: Both $F1$ and $F2$ show minimal changes, revealing that this formant level stays consistent regarding tongue height and backness throughout its production.

FOOT: $F2$ decreases slightly, while $F1$ formant elbow is still flat, suggesting a minimal phonetic retraction.

GOOSE: Formant levels $F1$ and $F2$ for this vowel remain stable across all time points, showing a steady articulation with slight variation in tongue position.

Conversely, formant elbows reveal that $F1$ remains relatively stable (flat/steady) for most vowels, while $F2$ shows slightly different formant levels, particularly in vowels like BATH and FOOT. This suggests that while the vertical tongue position (related to $F1$) remains consistent during vowel articulation, there is some horizontal movement (related to $F2$), indicating subtle shifts in tongue position toward the front or back of the mouth. The stability of $F1$ and $F2$ in vowels like FLEECE and GOOSE points to a more uniform articulation,

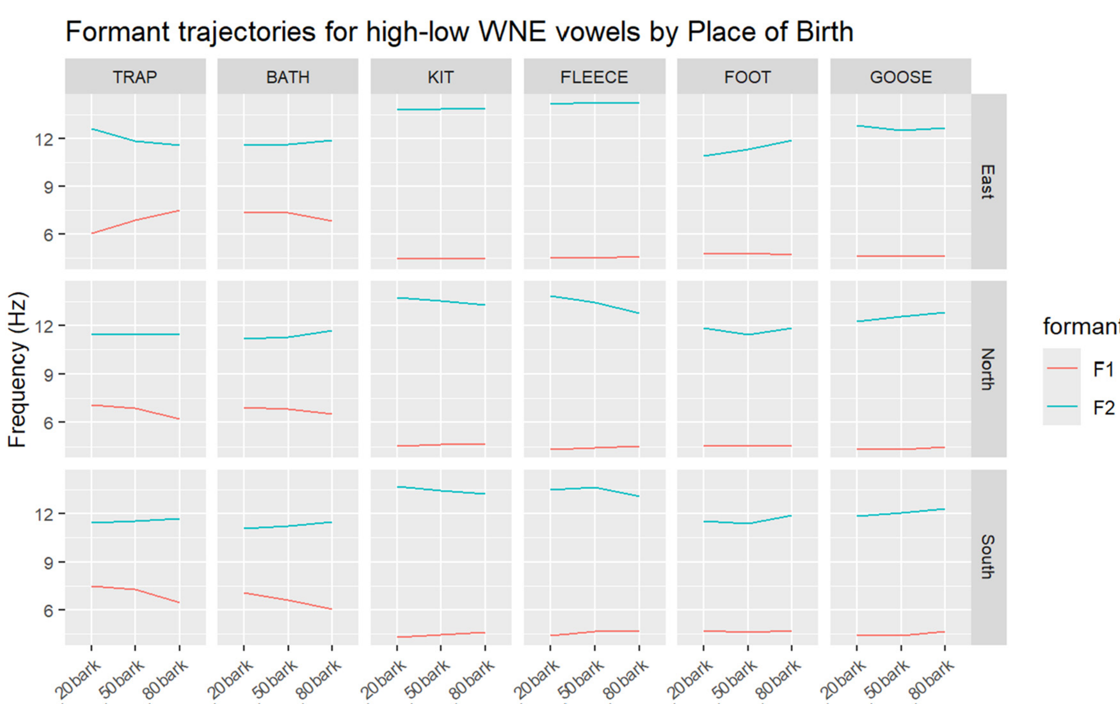

Figure 2: Bark normalized $F1 \times F2$ values for the TL, direction, and elbow (straight vs elbowed) of WNigE high-low vowels across 20, 50, and 80% of vowel durations across the regions: east, north, and west. The $F1 \times F2$ trajectory levels and directions show different levels across time points.

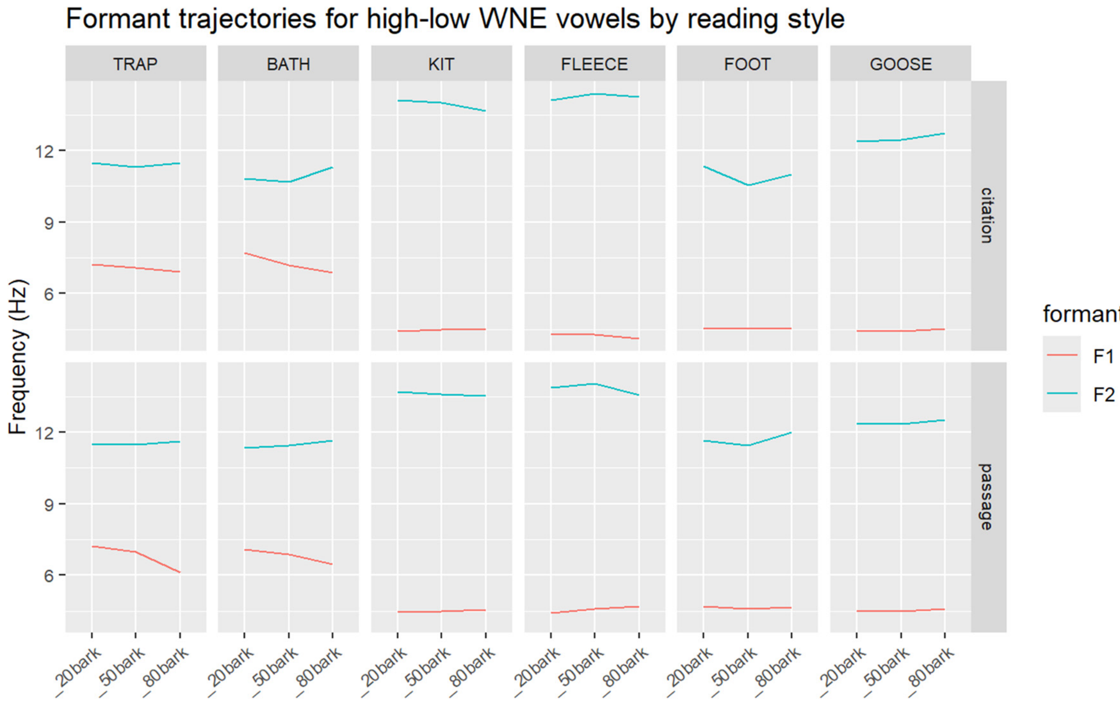

Figure 3: $F1 \times F2$ high-low WNigE vowels for the trajectory composite for different speech styles.

while vowels like BATH and TRAP show more dynamic changes, particularly in *F*2, reflecting regional or stylistic differences in pronunciation within WNigE. This analysis provides a clear overview of how vowel articulation varies across different vowels in WNigE, with implications for understanding the phonetic characteristics of this English variety.

Meanwhile, formant trajectories for these vowels in WNigE across different regions (east, north, and west) revealed different levels of variations. The formant frequencies *F*1 and *F*2 are plotted on the *y*-axis, while the time points (20, 50, and 80 Bark) are shown on the *x*-axis, indicating the changes in the formant frequencies over time for each vowel production.

For the WNigE speakers in the east, as shown in Figure 2, vowels like TRAP and FLEECE show relatively stable *F*1 trajectories, while *F*2 shows slight variation, particularly in TRAP, where *F*2 decreases over time. For vowels like FOOT and GOOSE, *F*2 remains higher across the time points, indicating a higher tongue position during pronunciation. The BATH vowel shows a slight decrease in *F*1, while KIT displays a stable *F*1 and a slight rise in *F*2. Comparatively, WNigE in the northern region showed more varied formant trajectories. For instance, TRAP has a rising *F*2, while BATH shows a stable *F*2 trajectory with a slight decrease in *F*1. KIT and FLEECE have relatively stable trajectories, with *F*2 showing minimal change. FOOT exhibited a more pronounced dip in *F*2, indicating a lower tongue position during this vowel's production. GOOSE shows a consistent *F*2 with a slight rise at 80%. Meanwhile, for WNigE speakers in the western region, TRAP and BATH show similar trends to the north, with a slight decrease in *F*1 and stable *F*2 trajectories. KIT and FLEECE have relatively flat formant trajectories, indicating a minimal tongue height or position change over these vowels. FOOT and GOOSE in the west show relatively stable *F*1 and *F*2 trajectories, with a slight rise in *F*2 for GOOSE toward the end of the vowel duration.

Importantly, across all regions, *F*1 generally shows less variation compared to *F*2, indicating that the vertical position of the tongue (related to *F*1) remains relatively consistent during vowel production, while the horizontal position (related to *F*2) shows more variation, particularly in vowels like TRAP, FOOT, and GOOSE. The differences in formant trajectories across regions suggest that place of birth influenced vowel pronunciation, with subtle variations in how these vowels are articulated in WNigE. This influence could be due to regional accents or dialects within the WNigE accent, which affect how vowels are produced.

In Figure 3, the formant elbows revealed trajectories for the reading style: citation/word list and passage. The formant trajectories, represented by lines, show the formant frequencies during the vowel production.

The formant movements revealed that the TRAP vowel slightly increased $F1$, with $F2$ remaining relatively stable across both reading styles. For BATH, $F1$ shows a slight decrease, while $F2$ remains steady, with a minimal increase in citation style at the 80% time point. Similarly, trajectories for KIT were relatively flat, with $F2$ slightly decreasing in word item list. FLEECE displayed a stable $F1$, with a slight decrease in $F2$. FOOT also showed a minimal rise in $F1$ and an upward trend in $F2$ within citation style. GOOSE has a stable $F1$, with $F2$ slightly increasing at the 80% time point.

The influence of reading style on these vowels is evident in Figure 3. However, for most vowels, the formant trajectories do not show significant differences between the word item list and passage reading styles, suggesting that the formant frequencies are relatively consistent across these conditions. The stability in the passage style compared to the citation style indicates more uniform articulation during connected speech. Importantly, vowels like FLEECE and GOOSE exhibit higher $F2$ positions, which suggest a higher tongue position closer to the roof of the mouth during production. Figure 3 shows the effect of style on vowel productions, offering valuable insights into the acoustic characteristics of these vowels.

3.2 FV

The analysis of FV across WNigE vowels revealed distinct patterns influenced by social and linguistic factors (Figure 4). Using MANOVA, the study analyzed $F1$ and $F2$ for FOOT~GOOSE, TRAP~BATH, and KIT~FLEECE, age category, syllable sequence significantly influenced FV for both $F1$ and $F2$ ($F1$: Pillai = 0.020, $F(4, 2{,}194) = 5.566$, $p < 0.001$; $F2$: Pillai = 0.012, $F(4, 2{,}194) = 3.416$, $p = 0.009$), while other predictors such as gender and education were not significant ($p > 0.05$). For TRAP~BATH, there was no statistically significant relationship with POB, gender, or education for $F1$ or $F2$ ($p > 0.05$).

However, FLEECE revealed a significant main effect of vowels and syllable sequence on FV in $F1$ (vowel: Pillai = 0.004, $F(2, 1{,}482) = 3.320$, $p = 0.036$; syllable sequence: Pillai = 0.009, $F(2, 2{,}946) = 3.5427$, $p = 0.01$), indicating variation in the onglide and offglide velocities across these vowels, while other predictors (e.g., age) remained non-significant ($p > 0.05$). These results suggest that FV varies by some linguistic and social factors, for example, education is not found to affect FV.

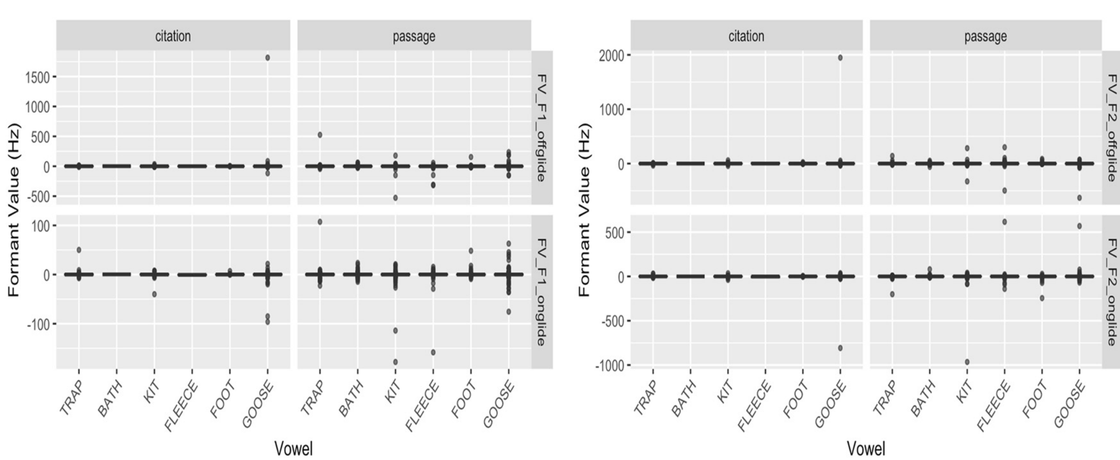

Figure 4: FV for $F1$_onglide, $F1$_offglide, $F2$_onglide, and $F2$_offglide for the six vowel lexical sets: TRAP, BATH, KIT, FLEECE, FOOT, and GOOSE.

3.3 VL

The separate repeated-measures ANOVAs were conducted for each vowel. The ANOVA on the VL values for KIT and FLEECE revealed a non-significant effect ($F(1, 1{,}440) = 2.742$, $p = 0.097$). Meanwhile, these vowels (KIT and FLEECE) are significantly different across POB ($F(2, 1{,}440) = 21.229$, $p < 8.2 \times 10^{-10}$, $\eta^2 = 0.03$) and reading style ($F(1, 1{,}440) = 4.511$, $p < 0.05$, $\eta^2 = 0.005$). The two-way interaction, vowels × reading style did not reveal any significant effect, ($F(1, 13) = 2.908$, $p = 0.088$, $\eta^2 = 0.01$). However, three-way interaction, POB × reading style × education ($F(1, 1{,}440) = 5.404$, $p < 0.05$, $\eta^2 = 0.006$). The three-way interaction with age category also revealed a significant main effect of age in the phonemic differentiation between KIT and FLEECE ($F(1, 1{,}440) = 4.849$, $p < 0.05$). The estimate value revealed that FLEECE ($\beta = 0.30$) is longer than KIT. The approximate effect size of this difference is Cohen's $d \approx 0.35$, which reflects a small-to-moderate effect, contrary to earlier claims (Akinjobi 2006, Jowitt 2018) that the WNigE does not have a phonemic distinction between KIT and FLEECE. Their arguments were premised on single-time vowel measurement without harnessing several point measurements or VL values.

Similarly, the ANOVA on the VL values for TRAP and BATH revealed a non-significant effect ($F(1, 554) = 0.817$, $p = 0.3665$, $\eta^2 = 0.001$). Meanwhile, these vowels (TRAP and BATH) significantly differ across POB ($F(2, 554) = 4.248$, $p = 0.01$, $\eta^2 = 0.02$). The two-way interaction, POB × age category, vowels × reading style, POB × education, and reading style × education, consistently revealed a significant effect ($p < 0.05$). The estimate revealed that BATH is 0.11 longer than TRAP. Though this relationship was not statistically significant, the estimate of 0.11 revealed that TRAP and BATH are not the same in VL. This result contradicts several investigations (Akinjobi 2006, Jowitt 2018) that claim that the WNigE accent does not have a phonemic distinction between TRAP and BATH. Their arguments consistently established that TRAP and BATH are the same vowels in WNigE.

The average VL for FOOT and GOOSE are 1.692 and 2.073, respectively (Figure 5). The ANOVA results for the VL comparison between the vowels FOOT and GOOSE, considering factors such as POB, gender, age category, reading style, and education, provide several insights. The main effect of vowels is not statistically significant ($p = 0.09$), but education is statistically significant ($p < 0.01$).

However, most interactions between vowels and other factors (such as POB, gender, age, and reading style) are insignificant ($p > 0.05$). This suggests that the effect of these factors on VL does not vary significantly between 'FOOT' and 'GOOSE.'

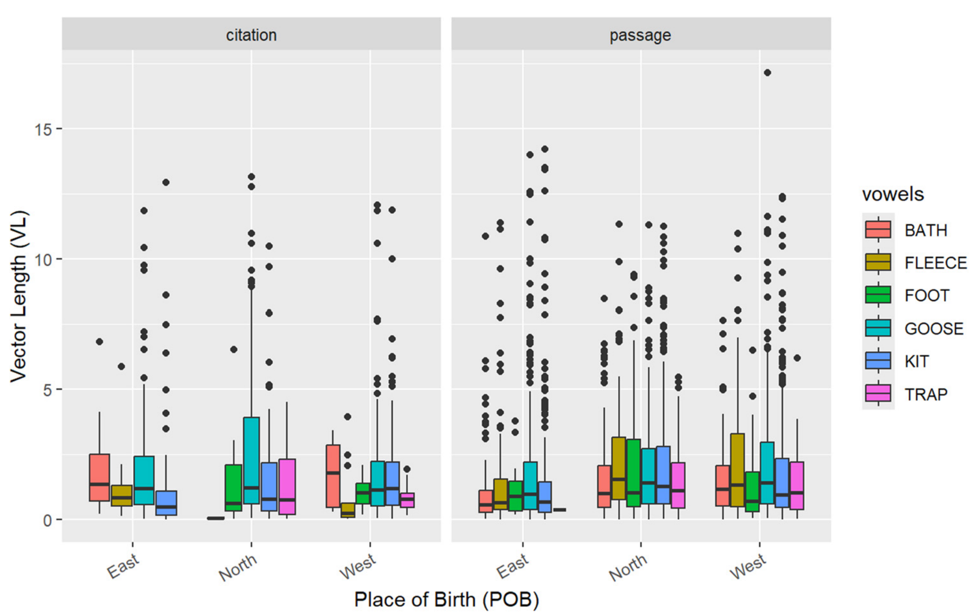

Figure 5: Inter-quartile range with mean VL values for WNigE high-low vowels with mean VL values for east, north, and west in citation/ word list and passage reading styles.

3.4 TL

As it was done for the VL measure, a repeated-measures ANOVA was conducted with the TL. The ANOVA results for FOOT and GOOSE across POB, gender, age, reading style, and education reveal a significant effect. POB has a significant main effect ($F(2, 1{,}057) = 6.774$, $p < 0.00119$, $\eta^2 = 0.02$). The estimate revealed that both north and west have higher TL than east. Notably, the WNigE in the north region ($\beta = 0.85$) and the west region ($\beta = 0.80$) are significantly higher than the eastern region, indicating that WNigE speakers from the northern and western regions have longer TL compared to those from the east ($F(2, 3{,}372) = 42.17$, $p < 2.2 \times 10^{-16}$, $\eta^2 = 0.05$). The statistically significant relationship supports the differences (north = $p < 2 \times 10^{-16}$; west = $p < 1.49 \times 10^{-14}$). Similarly, age shows a significant main effect ($p = 0.032$, $\eta^2 = 0.01$). These results indicate that regional and age-related factors play an important role in the production of VL for these vowels. Also, the consonant sequence (CVC and CV) significantly affects TL. Specifically, the closed syllable has a shorter TL than the open syllable ($\beta = -0.60$, SE = 0.11, $p < 4.10 \times 10^{-07}$, $d = 0.65$).

Also, there was a significant effect in the interaction of WNigE vowels and speaker's age ($F(1, 1{,}057) = 5.279$, $p < 0.05$, $\eta^2 = 0.01$) and the three-way interaction between POB, age category, and reading style ($F(1, 1{,}057) = 5.635$, $p < 0.01$, $\eta^2 = 0.02$). This indicates that the TL for FOOT and GOOSE is influenced by a combination of POB, age, and reading style. Additionally, the interaction between vowels (FOOT*GOOSE), reading style, and education is also significant ($F(1, 1{,}057) = 4.021$, $p < 0.01$, $\eta^2 = 0.015$), suggesting that educational background further modulates the influence of reading style on vowel articulation. These results show the importance of considering multiple sociolinguistic factors when analyzing vowel production, as they collectively explain the variation observed in the acoustic properties of vowels. Similarly, the ANOVA results for TRAP and BATH reveal significant effects of POB and interactions on the vowel TL.

Also, between TRAP and BATH, POB shows a significant effect ($F(2, 1{,}061) = 6.766$, $p < 0.001$, $\eta^2 = 0.02$), indicating that the region where the speaker is from significantly influences the TL of TRAP and BATH contrast. The interaction between these vowels and age category is also significant ($F = 5.279$, $p < 0.05$, $\eta^2 = 0.01$). Similarly, the age of the speakers influences the TLs of the TRAP and BATH vowels differently ($F(2, 1{,}061) = 3.449$, $p < 0.05$). Moreover, the three-way interaction shows that vowel type, age category, and reading style statistically influence TL (F-statistic = 5.635, $p < 0.01$). The syllable type similarly affects TL ($F(2, 1{,}061) = 13.215$, $p < 1.951 \times 10^{-06}$, $\eta^2 = 0.03$). However, the interactions between gender, reading style, education, vowels (particularly TRAP and BATH), POB, and age category were not statistically significant ($p > 0.05$).

The ANOVA results for KIT and FLEECE reveal significant effects of the POB and age category on TL and notable interactions between these factors and the vowels. Specifically, the effect of POB is significant ($F(2, 1{,}061) = 6.766$, $p < 0.001$, $\eta^2 = 0.02$), indicating that the region of birth influences the TL of these vowels. Additionally, age category significantly impacts TL ($F(2, 1{,}061) = 3.449$, $p = 0.05$, $\eta^2 = 0.01$), suggesting that the age group of the speaker also plays a role in how these vowels are articulated. However, gender, reading style, and education alone do not show significant main effects, indicating that they are not statistically significant on TL ($p > 0.05$). The analysis of TL by syllable sequence reveals significant effects. While there is no significant difference between no onset in VC and CVC sequences, the contrast between CV and CVC shows a statistically significant relationship (KIT~FLEECE [$F(2, 1{,}082) = 4.082$, $p < 0.01$, $\eta^2 = 0.02$]; TRAP~BATH and FOOT~GOOSE [$F(2, 1{,}082) = 4.082$, $p = 0.017$, $\eta^2 = 0.01$]). These findings suggest that the phonological environment influences TL.

The interaction between vowels and age category ($F(1, 1{,}061) = 5.347$, $p < 0.05$, $\eta^2 = 0.01$) and the three-way interaction between POB, age category, and reading style ($F(1, 1{,}061) = 7.828$, $p < 0.01$, $\eta^2 = 0.02$) are both statistically significant. These results suggest that the influence of POB and age category on TL differs depending on whether the vowel is KIT or FLEECE. The effect is further phonetically conditioned by reading style. This indicates that the production of KIT and FLEECE vowels is statistically significant across the region, age, reading style, and education.

3.4.1 Formant trajectories with GAMM

Data from each vowel production were examined with GAMM. We expect significant differences in vowel space by social and linguistic factors. In the original model, the results indicate that $F1$ values are statistically significant for vowel realization. For example, the model for $F1$ shows significant differences in formant levels between the reference vowel (BATH) and other vowels (Figure 6). The intercept ($\beta = 6.89$, $p < 0.001$) represents the average $F1$ value for BATH. Relative to BATH, all other vowels except TRAP show significantly lower $F1$ values, with FLEECE ($\beta = -2.19$, $p < 0.001$, $d = 0.95$), FOOT ($\beta = -2.14$, $p < 0.001$, $d = 0.93$), GOOSE ($\beta = -2.24$, $p < 0.001$, $d = 0.98$), and KIT exhibiting lower $F1$ levels ($\beta = -2.15$, $p < 0.001$, $d = 0.94$). TRAP has a slightly higher $F1$, indicating a marginally lower tongue position than BATH ($\beta = 0.08$, $p < 0.05$, $d = 0.04$). Smooth terms reveal that the $F1$ trajectory over time differs significantly for BATH ($p < 0.001$), FLEECE ($p < 0.01$), GOOSE ($p < 0.001$), and TRAP ($p < 0.001$) with $R^2 = 31.6\%$.

Similarly, POB influenced $F1$ for the speakers from the west compared to the north ($\beta = -0.05$, $p < 0.05$, $d = 0.10$). Gender differences revealed that male speakers had significantly lower $F1$ values than female speakers ($\beta = -0.22$, $p < 0.001$, $d = 0.40$). The smooth terms indicated significant temporal variations for most vowels, with timepoint effects for BATH ($p < 0.001$) and GOOSE ($p < 0.001$) standing out as particularly notable contributors to $F1$ dynamics ($R^2 = 32\%$).

Similarly, the $F2$ model highlights significant differences in tongue frontness across vowels, with the intercept representing the average $F2$ for BATH ($\beta = 11.47$, $p < 0.001$), FLEECE ($\beta = 1.97$, $p < 0.001$, $d = 0.85$), GOOSE ($\beta = 0.64$, $p < 0.001$, $d = 0.28$), and KIT ($\beta = 1.86$, $p < 0.001$, $d = 0.80$) have significantly higher $F2$ values compared to BATH. This shows a greater tongue frontness for other vowels except for BATH (Figure 6). However, the relationship of the frontness was not significant for FOOT ($\beta = 0.10$, $p = 0.103$, $d = 0.04$) and TRAP ($\beta = -0.03$, $p = 0.549$, $d = -0.01$). Smooth terms reveal significant temporal variation in $F2$ for FLEECE ($p < 0.001$), GOOSE ($p < 0.01$), and KIT ($p < 0.001$), while BATH shows no significant variation over time ($p = 0.889$). The model explains the variance in $F2$ at 21.3%, which indicates that tongue backness varies across vowels but to a lesser extent than $F1$ dynamics. In addition, POB strongly influenced $F2$ values, with speakers from the north ($\beta = -0.39$, $p < 0.001$, -0.34) and west ($\beta = -0.53$, $p < 0.001$, $d = -0.45$) showing significant decreases compared to the speakers from the East. Gender differences in $F2$ were statistically insignificant ($\beta = -0.01$, $p = 0.661$, $d = -0.005$). The smooth terms highlighted significant temporal variation for FLEECE ($p < 0.001$), KIT ($p < 0.001$), and GOOSE ($p = 0.003$), indicating dynamic changes in $F2$ trajectories over time ($R^2 = 23.3\%$).

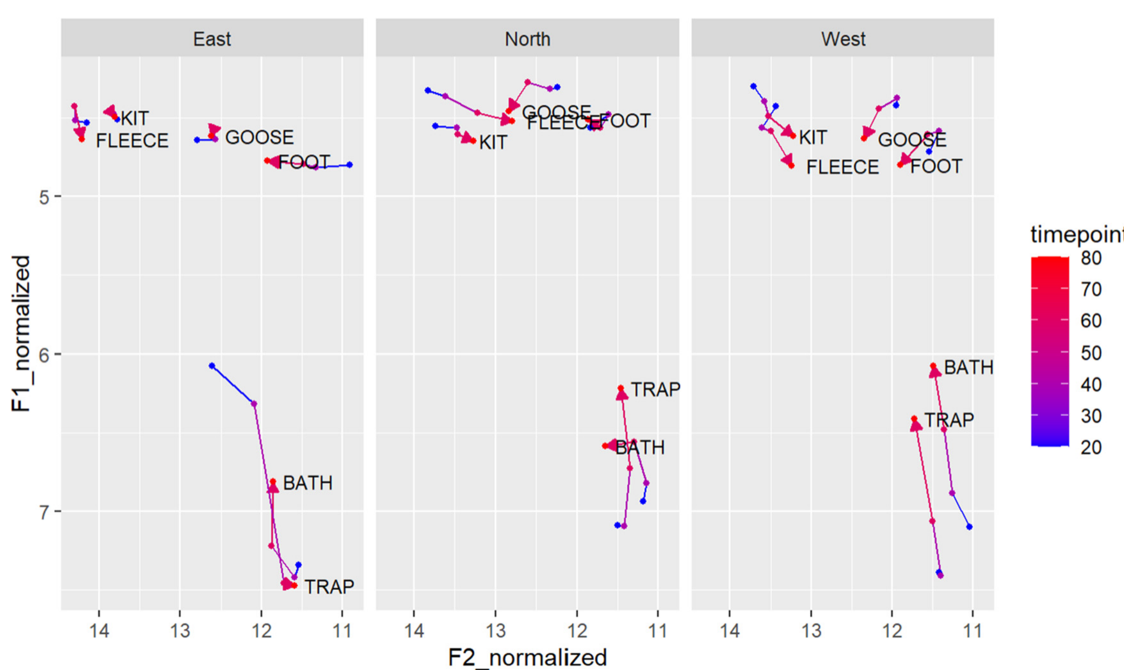

Figure 6: Predicted average trajectories for POB vowels. Each panel shows the predicted values from GAMM fitted to vowel production, with separate trajectories for the three regions.

The formant trajectories of vowels differ in distinct ways across the east, north, and west regions. In the east, KIT and FLEECE exhibit close and phonetic frontness, while GOOSE and FOOT are farther back (or retracted), with TRAP and BATH showing minimal vertical variation. In the North, the trajectories for GOOSE and FOOT show more phonetic overlap and less distinction than speakers in the East, while KIT and FLEECE maintain their frontness slightly closer (near merger). TRAP and BATH in the north display more vertical divergence, indicating greater variation in vowel height. In the west, KIT and FLEECE remain fronted but are more phonetically distinct than among the speakers in the north. At the same time, GOOSE and FOOT are phonetically distinct and exhibit different trajectories. TRAP and BATH show closer vertical alignment than in the north, suggesting more compression in their formant spaces. These results are consistent with Nagamine (2024) and Feimster Holt and Ellis (2018) that region affects formant trajectories.

4 Discussion

The results support Hypothesis 1, indicating that the vowels TRAP~BATH, KIT~FLEECE, and FOOT~GOOSE produced by WNigE speakers from the west, north, and east exhibit statistical significance in spectral change. Analyses of VL and TL showed that WNigE speakers in the north and west regions exhibited longer TLs for vowels like FOOT and GOOSE compared to the east. The GAMM analysis further revealed significant differences in formant transitions, with vowels like BATH and KIT showing varied $F1$ and $F2$ trajectories across regions. Our results also support the studies by Kiefte and Kluender 2005, Fox and Jacewicz 2009, Morrison 2013, which emphasized that formant transitions provide acoustic details about vowel identity beyond mid-point measurement. While previous studies (Mesthrie 2008, Jowitt 2018, Melefa 2019) explored regional vowel variation using mid-point formant analysis of NigE vowels, they overlooked dynamic spectral changes, which our study reveals. In addition, our results align with that by Isiaka 2019 and Jowitt 2018, who identified phonetic contrast in northern NE vowels.

Meanwhile, studies such as Tiffen 1974, Ajani 2007, Jamakovic and Fuchs 2019 framed NigE vowel variation as deviations from RP, reinforcing a prescriptive approach. Challenging this view, our study supports the studies by Low and Pakir 2018, Filppula et al. 2017, which argued that multilingual linguistic contexts exhibit inherent variation that should be analyzed sociolinguistically. This perspective acknowledges WNigE vowel variation as a natural outcome of Nigeria's unique linguistic ecology rather than as deviations from an external norm like RP.

Hypothesis 2 assume that the reading style influences the formant transitions of WNigE vowels. Our results show that reading style significantly influences vowel production. The formants in the word list were more stable (e.g., for KIT and FOOT), as evidenced by smoother trajectories and reduced variability. For instance, TRAP showed an upward trend in $F1$, and FOOT displayed a slight increase in $F2$ in word list compared to passage reading. The passage reading showed more consistent articulation across vowels, with FLEECE and GOOSE indicating less distinction These findings align with (Hillenbrand 2013, Kent and Vorperian 2018), who argued that word list explains vowel distinctiveness, while passage reading shows natural phonetic variability. Similar effects have been reported in other varieties of English (Morrison 2013, Fox and Jacewicz 2017), further confirming that reading style affects vowel articulation.

In addressing Hypothesis 3, using several-point measurements provided a more nuanced understanding of formant dynamics, supporting the hypothesis that these measures yield more detailed insights into vowel transitions than single-point measurements. GAMM results indicated significant differences in the amount and direction of formant movement for vowels such as KIT and FLEECE, with $F1$ trajectories showing temporal variation. The ability to model these changes across multiple time points revealed subtle differences in vowel dynamics that static, single-point analyses might miss in WNigE. This confirms findings from (Feimster Holt and Ellis 2018, Nearey 2013), which explain the importance of dynamic spectral analysis over static or mid-point measurements.

Our analysis similarly revealed that nine-point measures, as modeled through GAMM, provided a more detailed understanding of the shape and direction of formant trajectories, particularly for vowels with dynamic changes like KIT and FOOT. This reaffirms the analysis of vowel dynamics in the study by Fox and Jacewicz 2009 and Kiefte and Kluender 2005, who argued that vowel identity is shaped by the continuous movement of formant rather than static point, and that several-point measurements capture more variability and provide better insights into vowel identity. Together, the findings of this study emphasize the need for comprehensive analytical approaches to fully understand the phonetic and sociolinguistic factors influencing vowel production in WNigE speakers.

Our results showed the effect of some social factors. For example, Figure 2 reveals that the POB of the WNigE speakers shapes vowel articulation, particularly in the phonetic contrasts. Differences in formant direction, magnitude, and movement patterns were observed across WNigE speakers from the east, north, and west. However, gender is not significant. For instance, speakers from the north exhibited greater variability in $F2$ trajectories, particularly in TRAP and FOOT, indicating differences in tongue retraction. In contrast, WNigE speakers from the east displayed more stable $F1$ trajectories, with FOOT and GOOSE maintaining higher tongue positions. These findings highlight the role of regional accents in shaping vowel realization, suggesting that POB contributes to subtle phonetic restructuring within WNigE (Fox and Jacewicz 2009).

Age difference was another reliable social factor. The TL results indicated that older speakers exhibited longer TL values for FOOT and GOOSE, suggesting greater formant movement with age. Similarly, KIT and FLEECE showed age-related phonemic differentiation, where younger speakers exhibited more fronted realizations, while older speakers produced these vowels with slightly retracted trajectories. Similarly, FV for $F1$ and $F2$ was influenced by age of the speakers. This supports findings from previous research (Feimster Holt and Ellis 2018, Nagamine 2024) that age affects vowel dynamics, likely due to generational shifts in vowel production.

The effect size analysis for TL, VL, and formant dynamics further provided insights into the magnitude of variation beyond the statistical significance. For TL, POB and syllable structure had a small to moderate effect ($\eta^2 \approx 0.02–0.05$), which highlight regional and phonological influences on vowel trajectory. VL results for KIT and FLEECE also demonstrated small to moderate effects of POB and reading style ($\eta^2 \approx 0.03$ and 0.005, respectively), while the estimated difference in VL between the two vowels (Cohen's $d \approx 0.35$) suggested a phonemic distinction and challenges the claims of complete vowel merger in WigE. In the GAMM analysis of $F1$ and $F2$, several vowel contrasts (e.g., FLEECE vs BATH) exhibited large effect sizes (Cohen's $d > 0.8$) and it reveals strong articulatory differences in tongue height and frontness. Sociolinguistic factors gender and POB also had small to moderate effects in the GAMMs, which suggest that both social and phonetic conditions shape vowel realization in WNigE.

Speakers' educational levels also contributed to the phonetic contrast. The analysis of FV and VL revealed that education significantly influenced FOOT and GOOSE production, with speakers with higher education levels exhibiting more distinct phonetic contrasts. This suggests that exposure to formal education and possibly standard English varieties may influence articulatory precision in WNigE. However, gender did not emerge as a significant predictor of formant variation, implying that vowel articulation in WNigE may be more influenced by region, age, and education than by gender differences. The effect of the social factors supports (Filppula et al. 2017, Low and Pakir 2018) who emphasized the roles of the social factors in linguistic variable.

5 Conclusion

Analyzing vowel dynamics with several methods highlights the importance of estimating formant trajectories over time rather than relying solely on mid-point measurements. The formant trajectory approach provides a detailed formant shape of how WNigE vowels change over time, conditioned by the speaker's region, gender, reading style, and phonological context (Farrington et al. 2018). In our study, while VL and TL measure the amount of spectral change, they fail to track the direction or nonlinear changes in formants (Ferguson and Kewley-Port 2002, Fox and Jacewicz 2009). With GAMM, the results reveal linear and nonlinear formant change, shape, and directionality (Kirkham et al. 2019, Renwick and Stanley 2020, Nagamine 2024). Analyzing

WNigE vowels from VL, TL, and GAMM provides a better description of the vowels than relying on the mid-point that previous studies on WNigE reported. The results support (Cole and Strycharczuk 2019) that formants are influenced by linguistic (reading style and consonant sequence) and social factors (gender, age, region).

Unlike previous studies (Mesthrie 2008, Jowitt 2018), which claimed there is no phonetic contrast, our results provide evidence of phonetic contrast in WNigE. It is shown that there are phonetic contrasts for high and low vowels in WNigE (e.g., TRAP vs BATH, KIT vs FLEECE, and FOOT vs GOOSE) by exploring different formant dynamic analyses that are better than the mid-point (Nagamine 2024). The analysis of vowel formants reveals distinct patterns in tongue height and backness during vowel production. For TRAP, $F1$ decreases, indicating lowering formant levels, while $F2$ remains stable, reflecting a consistent tongue height. In BATH, $F1$ decreases slightly, and $F2$ increases at later points, suggesting forward tongue movement. KIT demonstrates stable $F1$ with a slight late increase, while $F2$ decreases, indicating a shift towards the back of the mouth. FLEECE exhibits minimal changes in $F1$ and $F2$, maintaining steady tongue positioning throughout. FOOT shows a flat $F1$ and a slight $F2$ decrease, indicating minimal tongue retraction. Finally, GOOSE remains stable across $F1$ and $F2$, reflecting consistent articulation with minimal tongue variation.

A review of earlier studies (Mesthrie 2008, Akinjobi 2006, Simo Bobda 2007, Dyrenko and Fuchs 2018, Melefa 2019, Oladipupo 2014) on WNigE reveals that they have not examined the effect of POB on the NigE vowel space. Our results, for example, highlight significant variations in the formant trajectories by POB, which indicate differences in vowel trajectories. The speakers in the north exhibit the highest TL variability. This indicates varied phonetic characteristics compared to the relatively consistent patterns in the east and west. This emphasizes the necessity of investigating WNigE speakers across regions to explore how regional, linguistic, and social factors shape vowel production.

Similarly, as this is the largest and most thorough phonetic description of vowels in WNigE, it can be used as a reference point for studies on other varieties of NigE; more acoustic–phonetic descriptions need to be done from the several vowel measurements rather than the mid-point on WNigE varieties. This approach enables a comprehensive comparison of vowels across NigE varieties, providing deeper insights into how vowel systems vary among different sub-varieties of NigE.

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Data availability statement: The sound files and corresponding time-aligned annotated textgrids of the datasets for this work are available in the OSF repository, https://osf.io/xzrnf.

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