# Static and Dynamic Analyses of the Back Vowels /uː/ and /ʊ/ in Singapore English

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## Abstract

This study explores static and dynamic spectral properties of /uː/ and /ʊ/ in wordlist and conversation styles across 21 Singapore English speakers. The acoustic data were analysed via LMMs and Pillai scores using F1/F2 midpoints, and GAMMs using five points. While static analyses show substantial overlap between the vowels without significant differences across speech styles, dynamic measures reveal nuanced differences in the height and shape of vowel trajectories. The findings contribute to the limited work on Singapore English back vowels and emphasise the need to combine static and dynamic measures to better capture sociophonetic variation in new Englishes.

**Index Terms**: Singapore English, back vowels, vowel overlap, speech style, individual variation, sociophonetics

## 1. Introduction

New Englishes or postcolonial Englishes refer to varieties of English spoken in countries with a colonial history and extensive language contact [1]. Singapore English (henceforth SgE) is a notable example, emerging from British colonisation with influences from major local languages such as Hokkien, Malay and Tamil, among others [2]. This sociolinguistic complexity has yielded substantial internal variation within SgE over time. For instance, the term encompasses such named sub-varieties as Singapore Standard English (SSE), Educated Singapore English and Singapore Colloquial English (SCE), distinguished on the basis of formality, functions and intended audience [2, 3], although the delineation between these sub-varieties is not always clear.

Given its diversity, SgE has received considerable attention in the literature [4], particularly regarding synchronic descriptions of its phonological features (e.g. [5-8]). However, sociophonetic research in SgE remains limited [9], with the exception of work on the front vowels /e/ and /æ/ (e.g. [10, 11]), and [12], which examined stylistic patterning of /ɒ/ and /ɔː/. This latter study revealed significant differences across speech styles—wordlist, reading passage, and interview—and age as a significant factor, with speakers aged 21-49 merging /ɒ/ and /ɔː/ and producing both vowels lower in the vowel space, indicative of a sound change in apparent time [12].

The majority of existing studies suggest substantial spectral overlap between /uː/ and /ʊ/ in SgE across different speech styles (e.g. spontaneous vs. read speech) [6, 13, 14] and sub-varieties (SSE vs. SCE [3, 7]). However, some scholars argue for an acoustic distinction between /uː/ and /ʊ/, particularly in SSE spoken in formal contexts (e.g. [3, 7]), although there is a lack of empirical evidence for this distinction. Previous studies also report differences in terms of the position of the two vowels in the vowel space. Both /uː/ and /ʊ/ are described as high back vowels in [6, 7], with /uː/ being spectrally higher but fronter than /ʊ/ [6]. In contrast, [15] suggests /uː/ to be phonetically more back compared to /ʊ/, and [14] observes fronting in both vowels. All this prior work has been based on a static target-based approach to vowel analysis, and none of them specified the exact points from which the formant estimates were taken (i.e. [6, 7, 13, 15]).

The integration of dynamic measures such as generalised additive mixed models (henceforth GAMMs) [16] in sociophonetics has provided valuable new insights into vowel spectral detail and temporal changes [17]. It has been shown that dynamic characteristics of vowels can change diachronically and that listeners attend to dynamicity in the speech signal (see [17]). GAMMs offer a particular advantage in measuring vowel overlap [18], enabling not only statistical comparison of formant trajectories between vowel pairs based on their shape and height, but also of spectral differences between factor groups [19]. Despite the widespread use of GAMMs across varieties of mainstream Englishes, such as American English (e.g. [20]), Australian English (e.g. [17]), British English (e.g. [21]), and New Zealand English (e.g. [22]), their application in New Englishes remains limited, with [9] being the only study on SgE thus far.

The GAMMs employed in [9] analysed trajectory plots and showed little difference between /uː/ and /ʊ/ in F1 over time for a group of ethnic Chinese Singaporean speakers, contrasting with relatively greater variation in F2. Specifically, /uː/ exhibited a backward then forward movement ending close to the starting position, while /ʊ/ showed consistent forward movement in the vowel space, characterised by a lower F2 at the trajectory onset but a higher F2 at the offset. Furthermore, /ʊ/'s F2 differed significantly between the 18-29 and 30-39 age groups, where the 18-29 group produced a spectrally fronter /ʊ/ with a consistently higher F2 trajectory overall. The findings also showed a large amount of interspeaker variation within the younger 18-39 demographic compared to the older 40-69 demographic. These results align with recent sociophonetic research on SgE /ɒ/-/ɔː/ vowels [12] and highlight the role of individual linguistic behaviour within group-level patterns.

Building on the findings of [9], who relied on sentence-read data, this study aims to investigate the impact of style on the acoustic properties of /uː/ and /ʊ/ via both static and dynamic measures. It focuses on young Chinese Singaporeans born after 1987—the year when English was mandated as the only medium of instruction in Singapore [23]. Focusing on controlled versus spontaneous speech, the research questions are: 1) What are the static and dynamic acoustic properties of the /uː/ and /ʊ/ vowels in SgE? 2) How do these properties vary across formal and controlled speech in a wordlist as compared to informal and spontaneous speech in a conversation?

## 2. Methods

### 2.1. Participants, procedure and materials

All participants were recorded by the first author in 2023 as part of a larger project investigating the production of monophthongal vowels in SgE. Here we present data from wordlist and conversational speech produced by 21 Chinese Singaporeans (11M, 10F; gender self-identified). By focusing on Chinese Singaporeans, we control for any variation attributable to ethnic differences (see [9]). None of the participants had ever lived in another English-speaking country at the time of data collection and reported no speech disorders. Participants were born between January 1987 and February 2005 (age x̄=26, s=4.57), and their educational backgrounds ranged from junior college and polytechnic to postgraduate levels. 18 participants self-identified English and two (F02, M01) self-identified Mandarin as their first or dominant language, while one participant (F09) listed both English and Mandarin as their dominant languages. Recordings were made using a RODE Wireless GO II dual-channel receiver and transmitter in a quiet room in a public library in Singapore. The audio files were exported in the app, RODE central, and digitised at a sampling rate of 48 kHz with a 24-bit resolution.

The wordlist included five repetitions of each target word (*foot, hood, food, goose*) embedded in the carrier phrase ‘He says ____ now’. The spontaneous speech was elicited through conversations between two participants, who had been encouraged to bring a friend and were asked to engage in a casual conversation on a topic(s) provided by the researcher (e.g. *What is your favourite breakfast?*) or a topic(s) of their preference. To ensure comparability between the datasets, only monosyllabic words with a consonant in the syllable coda were extracted from the conversational data (see https://osf.io/ctkym), resulting in a total of 796 analysed tokens (wordlist: 420; conversation: 376). Function words were excluded except for the modal verbs *could*, *should*, and *would.* These generally do not undergo reduction in SgE [8] and were accented in the present dataset.

### 2.2. Measurements and analysis

All speech files were force-aligned in *WebMAUS* [24], checked and corrected in *Praat* with default settings [25] prior to analysis using emuR [26] in R [27]. The F1/F2 estimates (in Hertz) were automatically extracted across normalised time at 20%, 35%, 50%, 65% and 80% of the vowel duration via *forest* with the parameters set according to speaker gender. Choosing the central portion mitigated the coarticulation effect of the surrounding consonants, while having five data points was visually more informative of the dynamics of the formant trajectories, and is also a prevalent method adopted in recent research (e.g. [28]). All data were visually inspected in EMU, with any datapoints subject to formant tracker errors hand-corrected or removed (~ 2.5%). Lobanov 2.0 normalisation [22] was applied, combining the data for 13 monophthongal vowels across time points, speech styles and speakers, following the assumptions of a vowel-extrinsic formula.

To measure the vowel acoustic properties, static measures such as the Pillai-Bartlett trace, or Pillai score, and Linear Mixed Modelling (LMM) were performed, followed by a dynamic analysis (GAMMs). Pillai scores are one of the conventionally applied approaches to measuring acoustic overlap, with values ranging from 0 (greater overlap) to 1 (greater distinction) [31, 32]. These scores were calculated with *tidyverse* [31] using normalised F1/F2 for group-level behaviour and raw formant values to further examine individual effects (after [34, 35]). LMMs were performed to determine the relationship between the predictors (speech style, vowel, their interaction) and the response variables (normalised F1/F2 estimates) with the inclusion of random effects (speaker and word) using lme4 [34] and lmerTest [35]. Tukey post-hoc tests were performed to locate the source of differences using *emmeans* [36]. GAMMs were used to model and analyse the normalised F1/F2 trajectories using the *mgcv* [37] and *itsadug* [38] packages. These incorporated fixed linear effects between predictors and the response variable (i.e. trajectory height) via parametric analysis, and smooth terms to capture non-linear effects (i.e. trajectory shape). Random smooths extended these smooth functions to random effects by allowing different curves for each value within a grouping variable [19, 21]. The current GAMMs were designed to capture the main effects and interactions; more complex models (e.g. those with item-by-effect random smooth terms) were discarded due to overfitting [39]. Following [21], log-likelihood tests for model comparisons were performed to evaluate predictors involved in interactions. A significant overall comparison was interpreted as an indication that the predictor affected the response variable. Visualisation of model summaries was also used to interpret the model outputs. Autocorrelation was not considered, as the autoregressive error model, which accounts for dependencies between neighbouring data points in the same formant trajectories, did not improve the overall fit (see [28]).

# 3. Results

### 3.1. Static results – vowel midpoint

Fig. 1 presents mean normalised F1/F2 plots for all vowels with the wordlist shown in the upper left panel and the conversation in the upper right panel. The lower panel focuses on the target vowels /u:/ and /ʊ/.

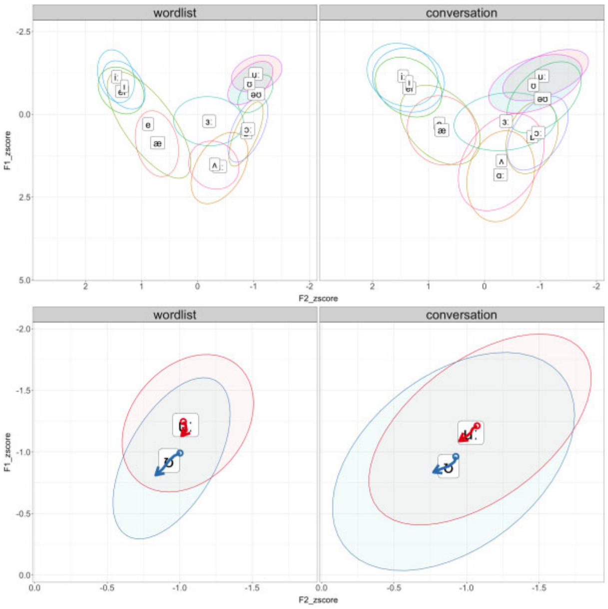

Figure 1: *Normalised F1/F2 estimates for all vowels (top panel) and the vowels /u:/ (red) and /ʊ/ (blue) (bottom panel) by wordlist (left) and conversation (right) with their mean F1/F2 estimates. Ellipses represent 95% confidence intervals; arrows (bottom panel) indicate the direction of the trajectory.*

Neither of the vowels exhibits fronting, as indicated by the position of /u:/ and /ʊ/ in relation to the mid back vowels (Fig.1, upper panel). For both speech styles, /u:/ appears spectrally higher and more back than /ʊ/, as indicated by its mean F1/F2 estimates (Fig.1, lower panel). There is some overlap for the two vowels, with the conversational data showing somewhat greater overlap in the F1/F2 vowel space. Pillai scores corroborated these observations with low scores, indicating substantial overlap between /uː/ and /ʊ/ in both the wordlist (0.11, $p<0.001$) and the conversation (0.05, $p<0.001$).

The LMM analysis further supported these findings by reporting non-significant effects of *vowel*, *speech style* and their *interaction* using formant estimates at midpoints, with the exception of *vowel* in F1 ($p<0.001$). To further explore these results, post-hoc tests were performed, revealing significant differences in F1 between /uː/ and /ʊ/ in both the wordlist ($p<0.05$) and the conversation ($p<0.001$). In other words, /uː/ is spectrally higher than /ʊ/ in both speech styles (Fig.1, lower panel). In addition, the random effect of *speaker* emerged as significant for F1 ($p<0.05$), indicating interspeaker variation in the phonetic realisation of vowels and potentially different patterns across the speakers.

### 3.2. Dynamic results – vowel trajectories and GAMM

The lower panel of Fig. 1 illustrates the average F1/F2 trajectories for /uː/ and /ʊ/. Both trajectories are short with a similar diagonal gliding (down left) movement across both speech styles. The trajectory for /ʊ/ is slightly longer and shows greater movement compared to /uː/, especially in the wordlist.

Expanding the dynamic analysis further, Fig. 2 shows GAMMs model predictions depicting changes in normalised formant trajectories of /uː/ and /ʊ/ across speech styles, with the baseline model including *vowel*, *speech style*, and their *interaction* as parametric factors, smooth terms over time (five measurement points) and smooth terms over time by *vowel* and by *speech style*, and random smooth terms (*speaker* and *word*).

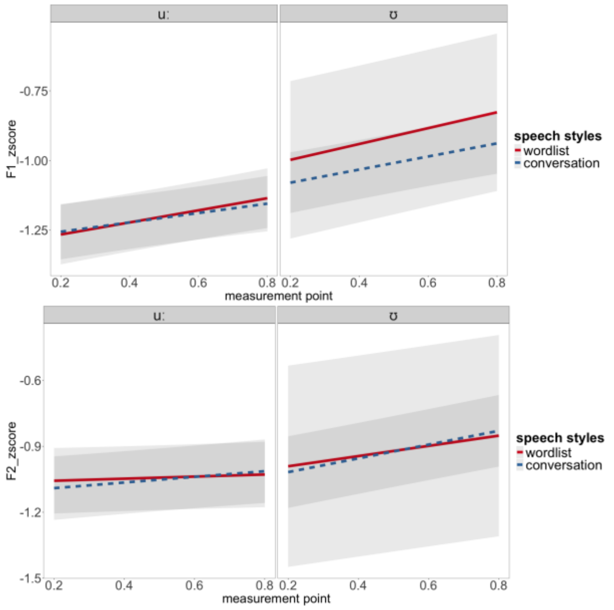

Figure 2: *Model predictions from GAMMs with 95% confidence intervals showing changes in normalised F1 (top) and F2 (bottom) trajectories of /uː/ and /ʊ/ across the wordlist (red) and conversation (blue).*

As illustrated in Fig. 2, /uː/ and /ʊ/ show greater differences in the height of F1 trajectory as compared to F2, with /uː/ exhibiting lower F1 values over time. Both vowels show little difference in F1 slope, but in F2, the almost horizontal flat line of /uː/ suggests little variation over time contrasting with /ʊ/'s positive slope. Greater formant differences are associated with steeper slopes. These observations were confirmed by the GAMMs output (see https://osf.io/paes9). Model comparisons between the full and nested models, which excluded all terms that involved the relevant predictor, revealed *vowel* as the only factor with significant effects for both F1 (vowel: $\chi^2(4) = 4.99$, $p<0.05$) and F2 (vowel: $\chi^2(4) = 8.75$, $p=0.002$). Specifically, /uː/ differed significantly from /ʊ/ in the overall height for F1 (determined via a parametric analysis, $p<0.01$), indicating that /uː/ is spectrally higher than /ʊ/ (i.e. lower F1, see Fig. 2 upper panel), consistent with the results based on the static measures. In addition, /uː/ differed significantly from /ʊ/ in the overall shape for F2 (determined via a non-linear analysis, $p<0.001$), with /uː/ exhibiting less dynamic movement over time (i.e. a nearly flat line parallel to the x-axis indicating minimal changes, see Fig. 2 lower left panel). In addition, *speaker* and *word* were significant for both formants (random smooth analysis, $p<0.001$), highlighting speaker-specific behaviour in the production of the two vowels (see §3.3) and lexical-specific effects in the variation of vowel production. Separate GAMMs were fitted to further tease apart acoustic differences between the two vowels in the respective speech styles. /uː/ was produced as a more backed vowel than /ʊ/ in the wordlist (parametric analysis for F2, $p<0.01$; see Fig. 2 lower panel), but with less dynamic movement over time for both F1 (i.e. non-linear analysis, $p<0.05$) and F2 ($p<0.001$). Fewer differences were observed in the conversation, with /uː/ being spectrally higher than /ʊ/ (i.e. F1, parametric analysis, $p<0.01$; see Fig. 2 upper panel) as the only difference.

### 3.3. Individual differences

The group-level analysis reported overlap between the two vowels, with /uː/ being significantly higher across the styles (LMMs analysis) and more back than /ʊ/ in the wordlist (GAMMs analysis). However, the significant effects for *speaker* via both LMMs and GAMMs analyses suggested interspeaker variability in vowel productions, which upon further inspection was characterised by three types of behaviour.

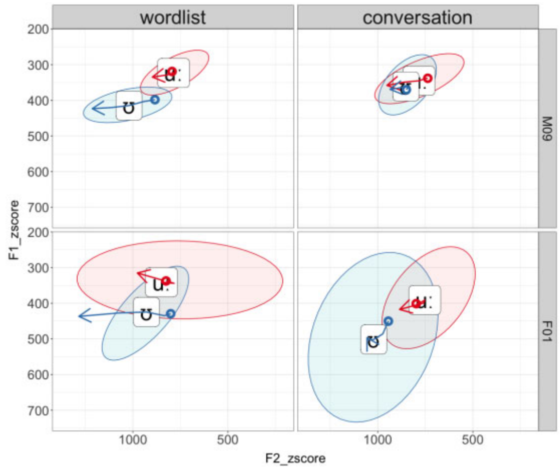

Figure 3. *Normalised F1/F2 estimates of /uː/ (red) and /ʊ/ (blue) for speakers M09 (top panel) and F01 (bottom panel) with their mean F1/F2 estimates. Ellipses represent 95 % confidence intervals; arrows indicate the direction of the trajectory.*

Among the 21 speakers, nine aligned with the group-level patterns (§3.1) and twelve exhibited two distinct behaviours that diverged from the group-level observations. Fig. 3 depicts F1/F2 estimates and trajectory plots for two speakers representative of these distinctive patterns. Speaker M09, whose patterning was also found among five other speakers, exhibited substantial overlap between /uː/ and /ʊ/ in the conversation (Pillai score of 0.13) and almost complete separation in the wordlist (Pillai score of 0.81). In contrast, speaker F01, representative of six other speakers, produced the vowels with a modest overlap in both speech styles and a moderately higher spectral distinction and a greater acoustic distance between the two vowels in the conversation (Pillai score: 0.45 wordlist, 0.59 conversation).

Further, unlike the short trajectories and relatively limited movement across speech styles reported for the vowels in the group-level analysis (Fig. 1, bottom panel), both M09 and F01 produced /ʊ/ with a longer trajectory than /uː/ in the wordlist, and a more dynamic movement overall for /uː/ in the conversation (Fig. 3). The vowels for speaker M09 exhibit uniform leftward trajectories in both speech styles, with a greater trajectory movement for /uː/ in the conversation, while the vowel plot for speaker F01 shows more dynamic changes in /uː/ in the wordlist.

## 4. Discussion and conclusion

Referring back to the research questions, the analyses based on static and dynamic measures revealed a high degree of overlap between /uː/ and /ʊ/, and this was the pattern for both controlled (formal) and spontaneous (informal) speech styles, with the controlled speech exhibiting moderately less spectral overlap. In particular for RQ1, while the static analysis showed none of the factors as significant except for /uː/ being significantly higher than /ʊ/ (i.e. F1), the dynamic measures revealed *vowel* as a significant factor overall. Specifically, /uː/ was more back and had a less dynamic trajectory over time than /ʊ/ in the wordlist as compared to the conversation.

Similar to [9]'s dynamic observations, our study showed greater variation in F2 for /ʊ/ and less spectral movement for the vowel /uː/, characterised by a flatter trajectory in both speech styles, However, instead of a fronter /uː/ at the onset as in [9], our results suggest that /uː/ starts and ends spectrally higher and more back than /ʊ/ in the vowel space. While these differences may stem from variation in sociolinguistic factors between the two studies (e.g. age), lexical difference, particularly for /uː/, could have contributed to the observed discrepancy. Comparing words from both controlled formal speech styles (i.e. our wordlist data and [9]'s sentence studio-recorded data) revealed that [9]'s three target words—*soon*, *soup* and *food*—primarily featured a /s_#/ environment. Research has shown that preceding coronal phonetic contexts, such as /s_#/, tend to induce greater fronting effect (i.e. higher F2) compared to non-coronal contexts [40]. While an in-depth analysis of word-specific effects is beyond the scope of the current study, differences triggered by words in these phonetic contexts underscore the importance of considering lexical effects in the future study.

RQ2 examines the effects of speech styles, and the group-level results align with previous studies [6, 7, 13, 15] which report substantial overlap between /uː/ and /ʊ/ across speech styles in SgE. However, unlike [14] and [6], the present findings did not observe fronting, with /uː/ being spectrally higher and more back than /ʊ/. Such discrepancies could also come from differences in participant cohorts: our study focused on Chinese Singaporeans rather than Malay Singaporeans [14] or mixed ethnic groups [6], supporting the recent observation about the significant ethnic effect on variation in SgE [9]. Moreover, the present study used vowel midpoints to perform static analysis, and this approach is different from previous studies (i.e. [6, 7, 13, 15]), potentially leading to different acoustic observations.

Individual variation was also present in the current study, similar to the acoustic observations of SgE front vowels reported in [10]. Individual differences were reflected in varied phonetic realisations for both vowels across speech styles: there were instances of overlap in casual speech only, or partial overlap in both speech styles, with the conversational data showing even more distinction than the wordlist. Vowel trajectories also showed differences in shape across individuals.

The distinction between the two vowels in the wordlist but not the conversation across the individuals could be motivated by hyperarticulation, as participants' attention to speech could have increased during a more formal task, such as reading the wordlist [10]. While the inverse acoustic pattern for this in F01 was unexpected, closer examination of the individual Pillai scores and words produced suggests a case of orthographic interference on vowel realisations. The wordlist reading task could have drawn participants' attention to orthography, leading to confusion in pronunciation, particularly for /ʊ/ words resembling /uː/ words with their 'oo' structure (e.g. *foot* versus *food*). The overall forward but limited downward trajectory, indicative of centralisation or fronting, also echoes trends observed in other Englishes (e.g. AmE [20]; BrE [21]).

Given its exploratory nature and a sample restricted to monosyllabic words, the conclusions rendered in this study are subject to further investigation. Moreover, the absence of durational comparisons between the wordlist and conversation may limit our understanding of the acoustic properties of the two vowels. Nonetheless, this study addresses a gap in sociophonetic understanding of SgE back vowels and stylistic and individual effects on phonetic variation and change among young SgE speakers. Furthermore, by using dynamic measures such as GAMMs in a New English, this research makes a significant contribution to the ongoing discussion (e.g. [17, 41]) about using both static and dynamic approaches to examine vowel properties and variability in sociophonetic research on varieties of English. Our future work will extend the examination to polysyllabic words, include duration as an additional factor, and explore the degree of rounding (F3 and the relationship between F2 and F3) through further acoustic analyses.

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