# VOWEL DYNAMICS IN THE SOUTHERN VOWEL SHIFT

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ABSTRACT: Southern varieties of English are known to be affected by the Southern Vowel Shift (SVS), which alters the positional relationship between the front tense/lax system. However, previous work on the SVS generally limits its focus to steady state formant measures. Possible links between these shifts and dynamic trajectory distinctions have largely been unexplored despite widespread recognition that Southern vowels are dynamic in nature. The current article uses data from three Southern states (Tennessee, North Carolina, and Virginia) to ask to what extent does spectral onset position (the typical measure of SVS participation) correlate with internal spectral dynamics in the SVS. Analysis methods include a series of spectral measures (vector length, trajectory length, spectral rate of change and vector angle), which capture vowel inherent dynamics and vowel directionality. Results support the utility of looking at dynamic measures to better understand the fuller extent of vowel changes that occur with the SVS and lend support to recent calls to include nonstatic measures in sociophonetic analyses more generally.

KEYWORDS: sociophonetics, spectral dynamics, Southern drawl, vowel inherent spectral change, regional variation

> Speech is not a static process, but an active one, and it is clear that many properties cannot be understood unless we examine their dynamic aspects.
>
> —Ladefoged and Maddieson (1996, 6)

THE SOUTHERN VOWEL SHIFT (SVS), a vocalic pattern characterizing English in the southeastern United States, has been well documented since Labov, Yaeger, and Steiner's (1972) early acoustic work (e.g., Feagin 1986; Thomas 1989, 2001; Labov 1991, 1994, 2001; Fridland 1999, 2001, 2012; Dodsworth and Kohn 2012; Fridland and Kendall 2012, 2015; Kendall and Fridland 2012; Koops 2014). In brief, the SVS refers to a number of changes that affect several parts of the vowel system, including the acoustic repositioning of the front lax and tense vowel pairs /i/ ~ /ɪ/ and /e/ ~ /ɛ/, high and mid

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back vowel fronting, and /aɪ/ monophthongization. The changes in the front vowel subsystem are particularly relevant in terms of distinguishing the contemporary Southern vowel system and will be the focus of the current work. The majority of sociophonetic research on vowels has focused on the first two formants (F1 and F2) and, in particular, static measurements of these formants at vowel nuclei. These are known to reflect primary cues to vowel identity (Labov, Yaeger, and Steiner 1972; Thomas 2001) and indeed represent key aspects of vowel quality. However, as the introductory Ladefoged and Maddieson (1996) quotation suggests, speech is an active process and its dynamic aspects need to be examined if we are to understand fully its properties. As such, recent sociophonetic work has considered a wider range of acoustic features in characterizing regional (and other) vowel differences (Fox and Jacewicz 2009; Wassink 2006, 2015). In this vein, the current project seeks to utilize measures that capture different aspects of vowel differences to better understand the role that dynamics play in the SVS.

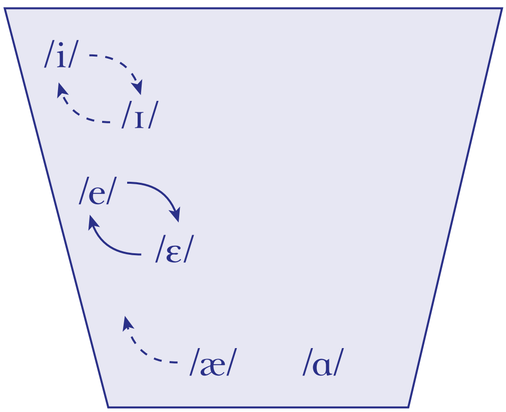
In folk linguistics, Southern speakers are often described as speaking with a "drawl," characterized by slow speech and "drawn out vowels" (Preston 1986, 1989, 1993), suggesting dynamics are socially salient cues for Southern speech. While little sociolinguistic research has empirically examined the "Southern drawl" (Allbritten 2011; Koops 2014), this kind of folk commentary likely draws, at least somewhat, from an acoustic reality. In fact, the front lax vowels /ɪ/ and /ɛ/, two of the vowels often undergoing SVS changes, are found to have longer durations in the South when compared to other regions (Clopper, Pisoni, and de Jong 2005; Fox and Jacewicz 2009; Fridland, Kendall, and Farrington 2014), as well as exhibiting "breaking," or becoming triphthongal (Feagin 1986; Allbritten 2011; Koops 2014). However, beyond sporadic mention of the Southern drawl (Sledd 1966; Feagin 1986, 1987; Wetzell 2000; Allbritten 2011) or studies of /aɪ/ monophthongization (Fridland 2003; Thomas 2003), very little linguistic work on Southern speech has focused on dynamics. The traditional characterization of the SVS is based on single point F1/F2 measures, usually in terms of a vowel nucleus or midpoint, despite wide acknowledgment that vowels in Southern speech are characterized by different dynamics than vowels elsewhere (Fridland 2012). It is surprising that there is a distinct lack of work done on vowel dynamic properties despite the potential relevance of trajectory information in maintaining phonemic distinctions for the front tense and lax vowel pairs (Kingston and Diehl 1994).

This leads to the present project, which focuses on a primary research question: to what extent is the SVS characterized by differences that involve dynamics and not just vowel positions? The current analysis addresses this question about the role of dynamics in the SVS by applying a suite of quantitative measures to production recordings from Southern speakers from three states with a focus on the front vowel subsystem. These measures capture (1) spectral onset position, (2) vowel inherent dynamics, and (3) glide directionality to examine how the SVS is characterized by vowel dynamics beyond typical nuclei measures. Results indicate that while single point measures can identify speakers as shifted or nonshifted, a number of other, nonstatic features also correlate with those measures, likely providing a more robust set of cues to Southern shifted speech. The quantitative measures that reflect dynamicity and glide direction, used together, provide a more complete encapsulation of what it means when we say a speaker has Southern shifted (SVS) vowels and better capture what specific linguistic cues are conveying the folk linguistic sense of "the drawl." While our substantive focus here is on the dynamic properties of the SVS affected vowels, this work offers more evidence of the import of looking beyond F1/F2 measures for sociophonetic studies of vowels for other language varieties.

## BACKGROUND

Though the South is also affected by back vowel fronting (as are many other dialects in North America), the Southern Vowel Shift primarily concerns the front vowel subsystem (see figure 1). The front vowels of the SVS are often conceptualized in terms of three primary stages or components, (1) the monophthongization of /aɪ/, (2) the centralization of /e/ and the peripheral-

FIGURE 1
Front and Low Vowels of the Southern Vowel Shift



ization of /ɛ/, and (3) the centralization of /i/ and the peripheralization of /ɪ/ (see Labov 1991 and Fridland 2012). /aɪ/ monophthongization is primarily a change in vowel dynamics and is often discussed in terms of the relationship between onset and offset position. This has been looked at in terms of dynamics in some prior work (e.g., Reed 2016). We do not look at /aɪ/ in the current analysis (and thus /aɪ/ is not included in figure 1), but rather focus on the front vowels. One of the most studied aspects of the SVS is the reversal of the front high and mid vowels (Labov, Ash, and Boberg 2006; Fridland 2012), but dynamic aspects are not well studied because this work has typically used static, single-point measurements (Labov, Ash, and Boberg 2006; Dodsworth and Kohn 2012). The front tense vowels /i/ and /e/ centralize, and the front lax vowels /ɪ/ and /ɛ/ become more peripheral (Labov 1991). Though the high and mid front vowels exhibit similar patterns, this acoustic reversal is much rarer in the high vowels and is more limited to the Inland South (Fridland 2012). Additionally, /æ/ is said to raise in Southern shifted speech (Koops 2014) and in some cases become triphthongal. While acoustic reversal is rare, the mid front lax and tense vowel nuclei show spectral overlap (in F1 and F2), and the degree of proximity of these two vowel classes has been used to quantify the extent to which speakers participate in the SVS (Labov, Ash, and Boberg 2006; Fridland and Kendall 2012; Kendall and Fridland 2012; Gunter, Vaughn, and Kendall 2017).

Clearly static F1 and F2 differences are important in describing the SVS pattern, with past research showing that the spectral position of the vowel nuclei for the front lax and tense pairs /i/ ~ /ɪ/ and /e/ ~ /ɛ/ correlates well to participation in the SVS (Fridland and Kendall 2012). As well, many cross regional studies show significant differences in formant frequency for the South compared to other dialect regions using single point measures (Clopper, Pisoni, and de Jong 2005; Labov, Ash, and Boberg 2006; Fridland and Kendall 2012), while other studies also show variability in the degree of SVS in different areas within the South (Fridland and Kendall 2012, 2015).

Some recent work on American English regional dialects has pointed to other characteristic features of Southern speech beyond what is captured by traditional F1/F2 measures, such as the role of vowel duration (Clopper, Pisoni, and de Jong 2005; Jacewicz, Salmons, and Fox 2007; Fridland, Kendall, and Farrington 2014). For the most part, this work on duration has found differences across dialects, mainly pointing to differences in tense/lax vowel length in Southern speech compared to other varieties (namely, longer lax vowels in the South). Fridland, Kendall, and Farrington (2014) found a relationship between spectral and durational measures that differs across regional varieties. For Southerners, a significant positive correlation between spectral distance and duration difference was found for vowels involved in the SVS pattern, while the correlation was negative for Northern and Western talkers. In other words, spectral overlap for vowel pairs correlated with duration overlap for Southerners, whereas the opposite pattern emerged for non-Southerners. This, of course, seems counterintuitive, as earlier research has suggested that duration tends to become more important as a disambiguating cue when spectral distinctions are small (e.g., Stevens 1959; Bennett 1968; Ainsworth 1972; Labov and Baranowski 2006). These vowel pairs are clearly not merged for Southerners, but our typical measures (e.g., static F1/F2 positions)—even duration (Fridland, Kendall, and Farrington 2014)—do not show a distinction because the lax and tense vowels overlap in their onset position, suggesting that dialects may be utilizing different phonetic cues for disambiguating classes for Southern speakers. Given its highly salient role in identifying Southern speech and the lack of durational and nuclear spectral distinction in SVS-affected vowel classes, investigating the role of vowel dynamics seems a logical next step. We suggest here that dynamics, like the duration relationship discussed above, may be utilized in a dialectally variable cue trading relation (e.g., Massaro 1987, 1998; Pisoni and Luce 1987). In other words, listeners will use a variety of auditory/acoustic information in processing speech, with various cues receiving different weight depending on dialect.

Work in recent years has begun to look more specifically at vowel dynamics and have uncovered differences across dialect regions (Hillenbrand et al. 1995; Fox and Jacewicz 2009; Benson, Fox, and Balkman 2011), across ethnolects (Risdal and Kohn 2014; D'Onofrio and Van Hofwegen 2015), and across generations in the American South (Koops 2010, 2014; Hinrichs, Bohmann, and Gorman 2013), all using methodologies involving measuring aspects of vowel trajectories. Such work suggests that vowel trajectory serves as an important aspect of vowel production.

Previous work examining the role of vowel dynamics in the SVS has been scarce, yet the little that has been done suggests this is a fruitful area for better understanding the SVS. In Piedmont, North Carolina, Risdal and Kohn (2014) focus on differences between European American English (EAE) speakers and African American English (AAE) speakers, using cubic splines of vowel formant trajectories to show that older EAE speakers' front lax vowels are more diphthongal and slightly raised compared to those of AAE speakers in the region. While their study was less about the SVS than it was about ethnolectal differences in North Carolina, they show that European American speakers have diphthongal F2 trajectories and that the trajectory peaks are earlier for both F1 and F2. In Houston, Koops (2014) attempts to connect the Southern drawl to the SVS by hypothesizing that a phonetic feature, which he calls a DELAYED INITIAL TARGET, is what unites the front vowel system of the SVS. With /æ/ as his primary evidence, Koops suggests that the initial gesture toward the nucleus target is delayed and that this lends to the perception that Southern vowels are long (89). This hypothesis warrants further investigation. Koops only visually compares trajectories, and the relationship between SVS dynamics and delayed initial targets remains an underexplored but suggestive hypothesis.

Part of the reason for the dearth of sociolinguistic research on vowel dynamics has been the difficulty in pinpointing precise measures that capture vowel dynamic differences that are important to listeners. In normal speech, factors such as context, speech rate, and vowel duration will all influence the degree and rate of spectral change (see Morrison and Assmann 2013). While certainly dynamic aspects of vowel quality are more complex to identify in terms of corresponding phonetic measures compared to static F1 and F2 values, we believe some dialectally contrastive aspects of spectral dynamics are possible to locate and might be related to some of the changes associated with the SVS (Feagin 1987; Wetzell 2000; Fridland, Kendall, and Farrington 2014). As mentioned above, recent studies, using different kinds of nonstatic analyses, problematize the single point (static) approach, which misses important spectral information that speakers use in recognizing different dialects (e.g., Wassink 2006, 2015; Di Paolo, Yaeger-Dror, and Wassink 2010; Van der Harst, Van de Velde, and Van Hout 2014; Docherty, Gonzalez, and Mitchell 2015). Related speech science methodologies drawn from the Vowel Inherent Spectral Change (VISC) literature might prove to be relevant for informing the study of spectral dynamics in sociolinguistics and dialectology and improve our understanding of the SVS (see Nearey and Assmann 1986; Morrison and Assmann 2013). In general, most work on the dynamic properties of vowels has focused on the task of identifying what aspects of spectral dynamics can be identified in the speech signal and which are perceptually available to listeners.

Though there are a wide range of possible approaches to selecting the measures most relevant to sociolinguistic variation in dynamics, the work most germane to the current study is the research by Fox and Jacewicz (2009; Jacewicz and Fox 2013). This work utilizes different VISC measures for comparisons of speakers from North Carolina, Wisconsin, and Ohio, who represent three distinct American regional varieties, namely, the South, the Inland North, and the Midlands, respectively. To capture both overall dynamic change across a vowel as well as how quickly the formant frequency changes over time, Fox and Jacewicz (2009) introduce three measures of spectral change: vector length, trajectory length, and spectral rate of change. Specifically, VECTOR LENGTH computes the F1 and F2 frequency change between onset (20%) and offset (80%) of a vowel. While similar plotting of the onset and offset of a vowel is common in sociophonetic work for diphthongs (see, e.g., Thomas 2001, 2011), some important aspects of vowel dynamics might be missed with this approach alone, for example, failing to capture dynamic variability between these points.

To address this, TRAJECTORY LENGTH calculates more finely the actual dynamic formant change between the onset and offset by summing individual component vectors at equidistant points between the onset and offset. Using such a measure, Fox and Jacewicz (2009) calculated frequency change at five points (= four vectors) temporally within a vowel and then summed those values. Comparing this to their vector length measure, Fox and Jacewicz (2009) found that vector length did, in fact, underestimate formant change. As an example of this, the vowel /ɛ/, which vector length did not indicate as significantly different across dialects in their work, showed a significantly greater trajectory length value for the South compared to the other sites. Finally, Fox and Jacewicz incorporate an additional measure, SPECTRAL RATE OF CHANGE, to calculate how fast spectral change occurs across the vowel's duration, by dividing the trajectory length by the duration. This measure aims to examine how different dialects might use the rate of spectral change rather than the amount of change to distinguish vowels in some way.

While Fox and Jacewicz (2009) found that regional affiliation resulted in significant differences for spectral measures, the spectral metric that proved most useful varied by vowel class. Each metric also exhibited different phonetic and dialect effects, making any consistent patterns difficult to discern. This suggests that while dynamics may play a role in defining regional variation, the type of dynamic shift most relevant in this variation may be dialect dependent. In other words, as Fridland, Kendall, and Farrington (2014) found that vowel duration and spectral overlap showed a positive correlation in Southern speech in contrast to a negative correlation in Northern and Western varieties, different aspects of vowel dynamics may also be at play in SVS patterns compared with Northern and Western vowel shift patterns. While Fox and Jacewicz (2009) found differences that are particular to their Southern speakers, they did not investigate whether these differences were related to the changes occurring with the shifts in the SVS pattern.

Little work on the sociolinguistic import of VISC (or relevant sociolinguistic measures related to VISC) has been done, which leads us to ask the extent to which the SVS is characterized by differences involving dynamics and whether we can identify, using various quantitative measures, which aspects best add to our understanding of the SVS.

## DATA AND METHODS

PARTICIPANTS. The data examined here come from a larger project on the production and perception of American English vowels across several regional dialects (Fridland and Kendall 2012, 2015; Kendall and Fridland 2012, 2016, 2017). In that project, both production and perception data were gathered from a series of participants across a number of research sites in the United States. A subset of 42 participants who supplied production data for the larger study are included in the present analysis. With the primary focus of this study being the SVS, we selected a broad sampling of 34 speakers from the three Southern sites in the main study; speakers from each site were chosen to represent a wide range of "Southernness," as captured by /e/ ~ /ɛ/ Euclidean distance values. We include 18 speakers recruited in Memphis, Tennessee, 8 speakers recruited in Raleigh, North Carolina, and 8 speakers recruited in Blacksburg, Virginia. As a group, speakers from the three Southern sites differ somewhat in their degree of SVS, with the Tennessee speakers generally being the most "Southern," followed by North Carolina and lastly by Virginia (see Fridland and Kendall 2015). For an interregional comparison, 8 Western speakers, recruited in Reno, Nevada, are also used; these speakers are expected to have reflexes of the so-called California Vowel Shift (CVS) (Labov, Ash, and Boberg 2006; Eckert 2008).

DATA COLLECTION. All speakers were recorded in a quiet university setting using a head-mounted microphone and a digital recorder. Following a perception experiment (described in Kendall and Fridland 2012, but not otherwise relevant here), participants were asked to read aloud from a reading passage and word list that covered a variety of phonetic contexts. While other studies from this larger project have largely focused on the word list production data, in this article we examine the reading passage data, which allows for more natural speech than the word list data but still yields identical lexical contexts across speakers. Many of the speakers examined here have been included in previous publications, but the vowel data are new measurements taken specifically with a focus on examining vowel dynamics.

Reading passages were force aligned using the Forced Alignment and Vowel Extraction (FAVE) software, developed at the University of Pennsylvania (Rosenfelder et al. 2011). The first author double-checked all vowel boundaries and manually shifted boundaries that were misaligned. All vowel measurements were made in Praat (Boersma and Weenink 2012) using a customized Praat script. Formant values (F1 and F2) were extracted at multiple points throughout each vowel, including the 20% point (onset), 50% point (midpoint), and 80% point (offset). We exclude the initial and final 20%

of each vowel token to minimize the influence of surrounding consonantal contexts, which are not the focus of the present analysis. Over 2,000 tokens of /i, ɪ, e, ɛ, æ/ were extracted for analysis (see table 1).

Formant values were normalized using the Vowels.R package (Kendall and Thomas 2010) in R, through the Watt and Fabricius modified method (Fabricius, Watt, and Johnson 2009), a vowel-extrinsic method that allows for normalization without collecting the entire vowel space. The modified Watt and Fabricius normalization method normalizes by placing vowels in reference to a centroid measure based on the three corners of the vowel envelope. In the current analysis, for the front corner vowel, the mean F1 and F2 values of /i/ were used as the minimum F1 and maximum F2 values. For the back high corner vowel, the modified Watt and Fabricius method uses the /i/ F1 value to represent both the F1 and F2 for the back high corner vowel; that is, /i/ F1 is used to extrapolate the high back corner rather than the properties of /u/, since /u/ is commonly fronted (see Fabricius, Watt, and Johnson 2009). And finally, the mean F1 and F2 values of /æ/ were used to represent the bottom corner of the vowel envelope.[1] The normalized formant values are computed by dividing F1 and F2 values for individual vowels by the centroid measure. In previous work based on these speech samples (e.g., Fridland and Kendall 2012, 2015; Fridland, Kendall, and Farrington 2014), we used Lobanov normalization, but that method requires full and balanced representation across the entire vowel space. The Watt and Fabricius method does not have this same requirement and requires only accurate means for each speaker's so-called corner vowels. Further, the Watt and Fabricius method results in similarly scaled normalized F1 and F2 values (outperforming Lobanov normalization in this regard based on preliminary comparisons),

TABLE 1
Token Counts by Vowel Class

| *Vowel Class* | *Token Count* | *Average Token Count per Speaker* |
|---|---|---|
| /i/ | 336 | 8.0 |
| /ɪ/ | 462 | 11.0 |
| /e/ | 644 | 15.3 |
| /ɛ/ | 255 | 6.1 |
| /æ/ | 351 | 8.4 |
| TOTAL | 2,048 | 48.7 |

NOTE: Despite the use of an identical reading passage across participants, token totals are not equal across all speakers (resulting in nonwhole number averages) due to occasional mispronunciations and omissions by the speaker.

which is important for applying Euclidean distance measures given their sensitivity to the scales of the units involved. The present project uses three measurement points, the onset (20%), midpoint (50%), and offset (80%), following previous work identifying vowel dynamic differences (e.g., Fox and Jacewicz 2009). Additionally, because this analysis examines different tokens than previous studies using these data, resultant values here for Euclidean distance between (means of) vowel categories are not expected to match exactly those reported in earlier analyses (e.g., Kendall and Fridland 2012; Fridland and Kendall 2015).

METRICS. In this article, we make use of four metrics that represent different aspects of vowel dynamicity and directionality. The first two, vector length and trajectory length, address formant change across a vowel; the third, spectral rate of change, incorporates duration to represent the rate at which a vowel changes over the course of its duration; and finally, we introduce a measure for the direction of the offglide, called the vector angle. One goal of this article is to examine the relative utility of these metrics in analyzing different aspects of dynamics and directionality. Additionally, these metrics are straightforward to calculate from extracted formant information at two (e.g., vector length) or three time points (e.g., the vowel onset, midpoint, and glide). Although many research reports, including those based on automatic extraction techniques like FAVE (Rosenfelder et al. 2011), focus on the analysis and presentation of single points within a vowel, data from multiple points are often extracted (even if not examined) as a part of the analytic process in sociophonetic vowel studies (Thomas 2011). As such, we hope to encourage other researchers to utilize measures already available from their analysis process, as discussed more below.

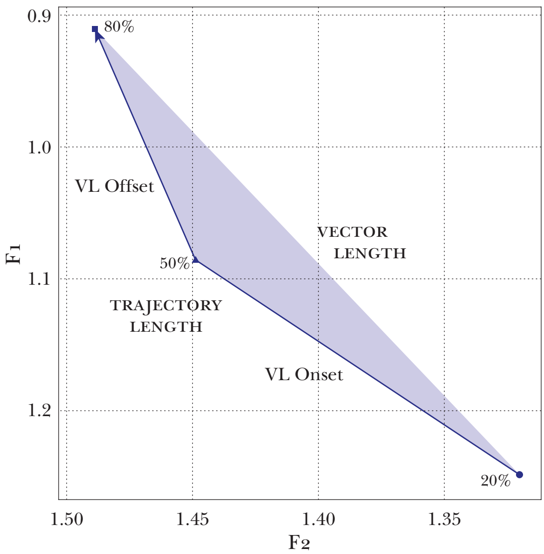
*Vector Length and Trajectory Length.* Vector length is the Euclidean distance from the onset (20% point) of the vowel to the offset (80% point) (Fox and Jacewicz 2009).

Equation 1. Calculating Vector Length

$$VL = \sqrt{(F1_{onset} - F1_{offset})^2 + (F2_{onset} - F2_{offset})^2}$$

Vector length paints a broad picture of dynamics and could be most useful when the most relevant information is the length of the diphthong, as with /aɪ/ monophthongization. An advantage is that it is a measure that could easily be implemented in studies that focus only on onset and offset measures of vowels. As such, our comparison of the performance of this measure compared to other measures of dynamics can help advise future research as to its utility.

FIGURE 2
Example /e/ Vowel with Vector Length and Trejectory Length




While useful, vector length underestimates the amount of dynamic frequency change across a vowel's duration by not accounting for nonlinear change. As many vowel trajectories display curves rather than straight vectors (e.g., curved or U-shaped trajectories such as that in figure 2), vector length does not capture such differences, which may yet be important acoustic cues to listeners. In other words, it may not simply be the length of the glide, but the shape of the glide that varies across vowels and dialects.

Trajectory length provides a more precise sense of vowel dynamicity. Recall that trajectory length calculates frequency change at multiple points temporally within a vowel and then sums those values. In the current study, we calculate a three-point trajectory length measure from each vowel by adding two vector segments, the onset vector length (from 20% point to 50% point) and the offset vector length (from 50% point to 80% point).

Equation 2. Calculating Trajectory Length

$$VL_{onset} = \sqrt{(F1_{onset} - F1_{midpoint})^2 + (F2_{onset} - F2_{midpoint})^2}$$
$$VL_{onset} = \sqrt{(F1_{midpoint} - F1_{offset})^2 + (F2_{midpoint} - F2_{offset})^2}$$
$$TL = VL_{onset} + VL_{offset}$$

This trajectory length measure differs from Fox and Jacewicz's (2009) in that they used a five-point (four segment) trajectory length, with points every 15% of the vowel from 20% to 80% of the vowel's duration. In a preliminary analysis of our data, we found that using a three-point (two vector) trajectory length correlated better to formant position (Euclidean distance) than a five-point trajectory length, as well as a 13-point trajectory length (with points every 5% of the vowel). The three-point trajectory length measure is highly correlated with the more complex trajectory length measures. That is, having three points is much better than having two, but higher orders than three (e.g., five and 13) do not seem to have further advantages in the current analysis. Fox and Jacewicz (2009) were interested in finding a more accurate tracking of dynamicity of each vowel, which motivated their five-point measurement. Our interest in the SVS led us to use this slightly simpler representation, as well as our hope that a three-point measure, if equally useful, would provide a more accessible measure for typical sociophonetic analyses that extract formant measures only at the onset, midpoint, and offset points.

As we would expect, for each vowel token, trajectory length will always be longer than vector length, since trajectory length can never be less than vector length and has vector length as its possible minimum value. So again, trajectory length represents a more fine-grained view of the vowel, while vector length brushes a broader stroke of vowel length. For other vowel classes and language varieties, the higher order trajectory length measures might be more appropriate, and the methods for calculating the current study's trajectory length can be applied in the same way.

*Spectral Rate of Change*. Spectral rate of change calculates how fast the spectral change occurred across a vowel's duration. Neither vector length nor trajectory length incorporates a temporal aspect, thus the spectral rate of change measure may help to determine if time-varying dynamics are part of the dialect complex. Spectral rate of change is calculated by dividing the trajectory length by the percent of the vowel being measured (here 0.60, or 60% of the vowel, from 20%–80%) multiplied by the raw duration (see equation 3).

Equation 3. Calculating Spectral Rate of Change

$$\mathrm{ROC} = \mathrm{TL}/(0.60 \times \mathrm{duration})$$

A higher spectral rate of change value means there is more dynamic movement within the vowel's duration, while a lower one means slower movement. This spectral rate of change measure is straightforward to implement, given that most automatic extraction programs (e.g., FAVE-extract) also extract durational information. (The key here is to only include the duration between the 20% and 80% extraction points.)

Regarding our current research question, while these measures—vector length, trajectory length, and spectral rate of change—are direction independent, they may be related to the ways in which Southerners distinguish vowel classes and, as such, may provide insight into how Southerners' vowel classes are phonetically distinct.

*Vector Angle*. Traditionally, sociolinguistic and phonetic descriptions of diphthongs make qualitative reference to glide directionality (e.g., "upgliding," "ingliding") but little work has quantified this directionality. Vector angle, a measure of the angle of the vowel onset to offset, quantifies glide direction. Vector angle is calculated on a per token basis by using polar coordinates (rather than Cartesian coordinates). In a polar coordinate system, there are two numbers, $r$, a radial coordinate (i.e., $r$ = vector length) and an angular coordinate, $\theta$, from a reference point (the pole). The polar ray itself is the vector length (see equation 1), while $\theta$ is calculated using the arctangent of the offset values minus the onset values (see equation 4). By subtracting the onset points from the offset points for F1 and F2, we set the reference point of the polar ray to $(0, 0)$. We converted the output (in radians) to degrees and took the inverse of those values to reorient the data to reflect the traditional way vowels are plotted (with larger values running right to left and not left to right). To account for down and ingliding vowels, the angles were put on a scale of −180° to 180° to avoid vowel comparisons across the 0°/360° boundary.

Equation 4. Calculating Vector Angles

$$\theta = \text{arctangent}((F1_{offset} - F1_{onset})/(F2_{offset} - F2_{onset}))$$

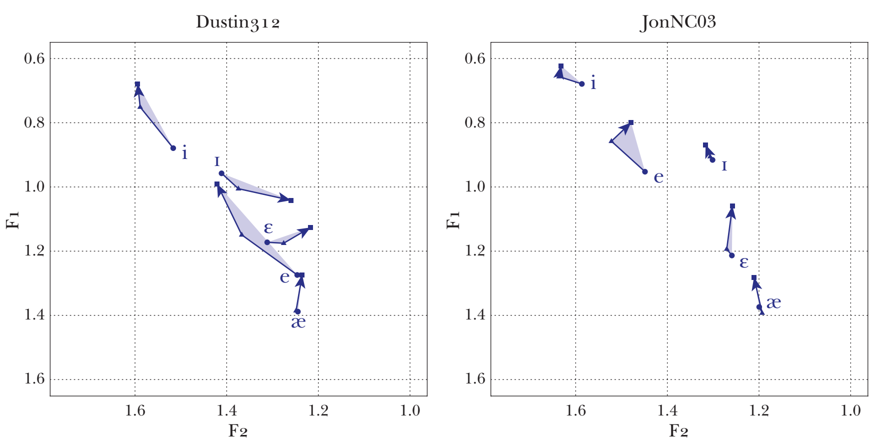
While the present analysis only uses vector angle as a measure of the angle from a vowel's onset to offset, we note that this could be implemented for any chosen vector, including to calculate the angle from vowel onset to midpoint or between different vowel classes to show relative positioning (as in Fabricius 2008).

## ANALYSIS

Our primary research question is to what extent the SVS is characterized by differences that involve dynamics and not just vowel positions. To pursue this, in the sections below, we examine more deeply the role of glide dynamics, as measured by vector length and trajectory length, the speed of frequency change, measured by spectral rate of change, and vowel glide direction, measured by vector angle, and we look at how these measures correlate with more traditional (F1/F2) measures of SVS participation. But first, we begin our analysis by qualitatively looking at two Southern speakers, one who exhibits a clear SVS pattern and one who does not. These two plots illustrate the point that the SVS likely interacts with dynamicity and with vowel directionality.

Since our data are collected in three different sites in the South, and since the SVS is known to be variable across the South, we would expect a range of variability with regard to how the SVS is instantiated in individual speakers' systems. In figure 3, two participants, Dustin312, from Memphis, and JonNC03, from North Carolina, are plotted.[2] (The names used here are the original speaker codes used in Fridland and Kendall's 2012 study, and we continue the use of these codes for continuity with previous papers.) Dustin312 has a clear SVS-shifted system. His /e/ and /ɛ/ vowel nuclei are reversed, and his /i/ and /ɪ/ are proximal. We see similar trajectory directions for the front tense vowels, /i/ and /e/ (both high and front gliding) with long glides, while both /ɪ/ and /ɛ/ are back gliding. When comparing Dustin312's front vowels to JonNC03, who has a much less shifted system, these SVS features appear in stark contrast. For JonNC03, all glides are spectrally shorter and the front lax and tense pairs are quite distinct. The front tense vowels exhibit a similar glide direction when compared to Dustin312, but JonNC03's upgliding lax vowels are distinct. One other notable aspect is the similarity of the /æ/ vowel class, which is slightly more fronted for Dustin312, but in both cases, there is a similar glide direction. Again, these two representations of two speakers, one more strongly shifted and one exhibiting little SVS shift, give us a clear example that if we only look at the vowel nucleus point, we miss out on differences that might be important and relevant to understanding the SVS.

FIGURE 3
Vowel Plots for Dustin312 (more shifted) and JonNC03 (less shifted)



In terms of degree of participation, Fridland and Kendall (2015, 3) found more "classic Southern features" in the Tennessee data (e.g., Dustin312), such as more proximate /e/ and /ɛ/ vowel classes. As a way to quantify the SVS, Fridland and Kendall (2012) used a Euclidean distance formula (equation 5), which calculates the distance between the means of the /e/ and /ɛ/ vowel classes on a speaker-by-speaker basis.

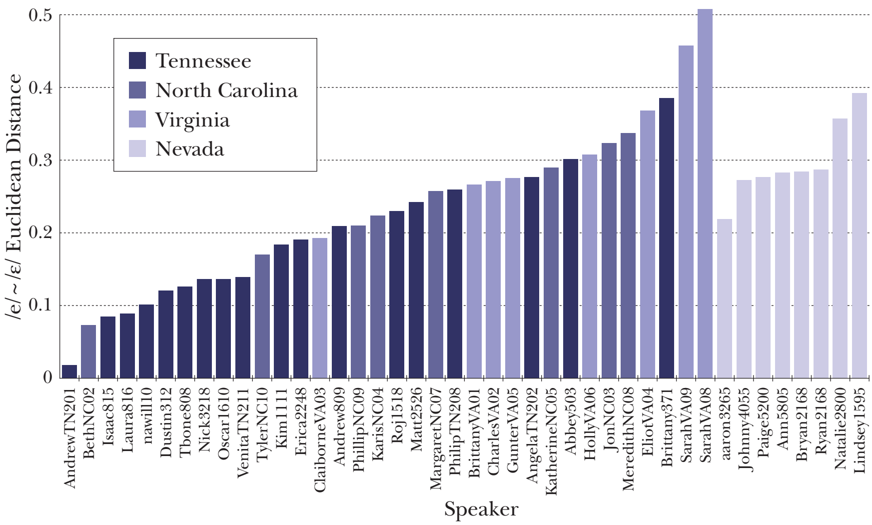
Equation 5. Calculating Euclidean distance (between /e/ and /ɛ/)

$$ED_{/e/\sim/\varepsilon/} = \sqrt{(F1_{/e/} - F1_{/\varepsilon/})^2 + (F2_{/e/} - F2_{/\varepsilon/})^2}$$

Since the output of this Euclidean distance measure is always positive, this quantification shows how proximate the mean vowel classes are for their speakers (regardless of spectral reversal). More proximate vowel classes result in a smaller Euclidean distance. Kendall and Fridland (2012, 296) checked this Euclidean distance metric against impressionistic analyses of each speaker's SVS system and found that the speakers with more proximate vowel pairs were indeed the ones who sounded the most Southern. They went on to use this mid front vowel Euclidean distance measure as a more general proxy for "Southern shiftedness." Similarly, Labov, Ash, and Boberg (2006) show that speakers with more proximate mid front vowel classes have a stronger degree of participation in other SVS features. Recently, Gunter, Vaughn, and Kendall (2017) confirmed that a speaker's /e/ ~ /ɛ/ Euclidean distance correlates with listeners' ratings of Southernness for a wide range of vowel classes. As such, we use /e/ ~ /ɛ/ Euclidean distance as a speaker-level proxy for SVS participation. This measure will be used as a baseline for SVS participation (along with more typical, static, dimensions) for comparisons to different dynamic and directional measures. The speakers in our data set range from having very proximate /e/ ~ /ɛ/ vowel nuclei means (scores close to 0) to distinct vowel class means. Figure 4 shows the 34 Southern speakers ordered by mean /e/ ~ /ɛ/ Euclidean distance. This measure, which will be referred to throughout the article, is the distance between vowel class means on a per speaker basis. A score of 0 indicates that the means of /e/ and /ɛ/ are the same (more shifted speakers), and the further the value moves away from 0, the more distinct are the vowel class means (less shifted speakers). Nevada speakers, who are situated firmly within the Western dialect region (Labov, Ash, and Boberg 2006) are included in figure 4 for reference. While we do not want to imply that the distance between /e/ and /ɛ/ is a meaningful measure for these Nevada speakers, or for speakers from other dialect regions more broadly, we do note that they have much more distant Euclidean distances than many, but not all Southerners.

In the remainder of this section, we will look at vector length, trajectory length, spectral rate of change, and vector angle measures to determine how

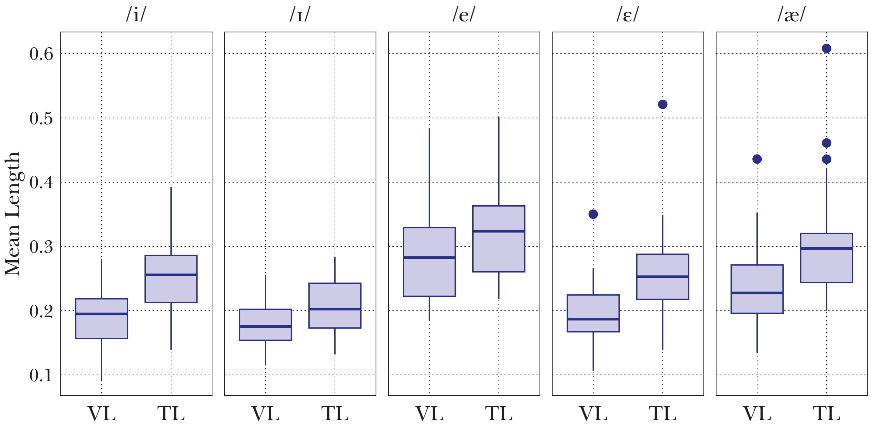
FIGURE 4
Speakers Ordered by /e/ ~ /ɛ/ Euclidean Distance




these metrics compare across vowel classes, but more importantly, how they compare and correlate with more traditional SVS measures used in sociolinguistics to determine what, if any, additional cues such measures might add to the picture of distinguishing our Southern speaker sample beyond static F1/F2 measures.

VECTOR LENGTH AND TRAJECTORY LENGTH MEASURES. We turn now to examine the first two of our quantitative dynamic measures, vector length and trajectory length. We first examine how they compare to each other across vowel classes, and then how these metrics relate to other measures of SVS participation, a question that went unexplored in Fox and Jacewicz (2009). Vector length and trajectory length are represented in a series of box plots in figure 5, separated by vowel class. By mathematical necessity, we expect trajectory length to be at least equal to vector length, but our main interest here is in whether we find that there is more variability captured by trajectory length than by vector length alone. That is, while trajectory length will be minimally equivalent to vector length, we include it because it should better capture internal dynamics that often occur between the onset and offset (e.g., triphthongal or curved shapes) and might serve as cues to the listener. Repeated measure analyses of variance (ANOVA) comparing vector length to trajectory length for each vowel class confirm that for each vowel class except /e/, trajectory length is significantly longer than vector length (/i/ ($F = 22.79$, $p < .001$), /ɪ/ ($F = 9.138$, $p < .01$), /e/ ($F = 3.303$, $p = .07$), /ɛ/

FIGURE 5
Vector Length and Trajectory Length Means by Vowel Class for Southern Speakers



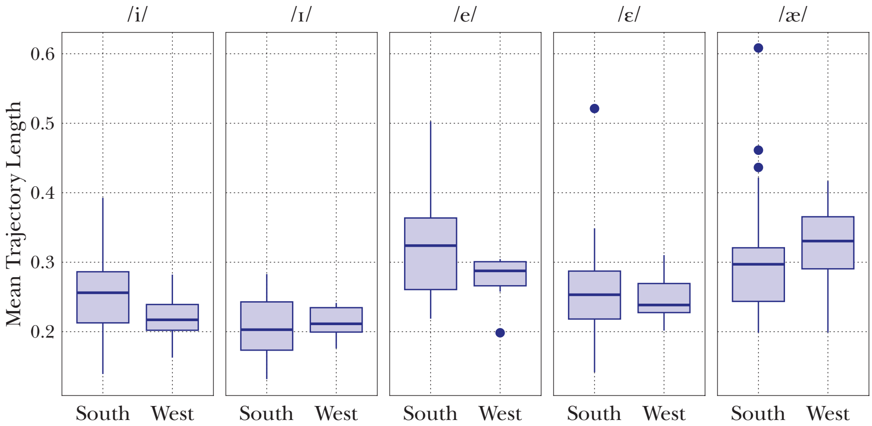

($F$ = 17.61, $p < .001$), /æ/ ($F$ = 12.68, $p < .001$).[3] Indeed, there is more variability within the vowel than an Euclidean distance measure between vowel onset and offset alone captures.

While our previous work (e.g., Fridland, Kendall, and Farrington 2014) has suggested that onset position and duration in the SVS do not always clearly differentiate, for example, /e/ and /ɛ/, we see here that a measure of vowel dynamics, trajectory length, could be a cue that might help to disambiguate vowel classes. In this case, /e/ clearly exhibits a longer trajectory compared to /ɛ/, in both vector length ($F(66)$=36.58, $p < .001$) and trajectory length ($F(66)$=14.41, $p < .001$). Similarly, for the high vowels, Southern /i/ and /ɪ/ vector length measures are not significantly different, but the trajectory length of /i/ is indeed longer than that of /ɪ/ ($F(66)$=11.58, $p < .01$). These differences between the lax and tense vowel pairs for trajectory length, which are most similar in terms of spectral onset position for Southern speakers, suggests that they could be used to cue vowel identity. We will return to this potential relationship between formant position and dynamicity shortly, but first we ask whether Southern vector length and trajectory length measures set them apart from non-Southern speakers.

To get a sense of how vowel dynamics play a role in characterizing Southern speakers, we compare the trajectory lengths of Southern speakers to Western speakers. Since it has been found that trajectory length is a more precise measure of a vowel's trajectory (Fox and Jacewicz 2009) when compared to vector length, we ask whether this variance is due to some aspect of vowels that is related to Southern speech in general, or whether

FIGURE 6

Trajectory Length Means by Vowel Class for Southern and Western Speakers




the variance captured represents something more inherent about vowel variation. In figure 6, trajectory length means for our Southern and Western (Nevadan) speakers are plotted by vowel class. Separate ANOVAs for each vowel class based on speaker means were computed to test the influence of region on trajectory length. Across each of the vowel classes, there are no significant differences between the South and the West. (ANOVA tests range from $F(1, 40) = 3.015$, $p = .09$ for /e/ to $F(1, 40) = 0.064$, $p = .80$ for /ɛ/.)

When comparing regions, we see that dynamic measures of trajectory length for the South pattern longer than the West for the tense vowel classes, but these differences are not statistically significant. In fact, across each of the front vowel classes, there are no significant differences between the South and the West, suggesting that for trajectory length, there are not major differences between regions. So even though we know that trajectory length is a more precise measure of a vowel's trajectory (Fox and Jacewicz 2009), it does not exhibit differences across the regions, at least for the South and West. But, as we know, there is a wide amount of variation in the South, as evidenced by figure 4 above. Perhaps the South is using trajectory length differently, and rather than a group-level analysis, more important variation is found on a speaker level. Also, the SVS most strongly differentiates the South with the North (i.e., speakers with the Northern Cities Shift pattern, not Westerners), and it may be that a comparison of those two regional patterns might reveal more significant differences in these metrics.

Given the overlap that we often find in static measures for these vowels, a longer vector or trajectory length for /e/ and /i/ in the South might be one source that listeners use to help disambiguate the front vowel classes. Perception data, of course, would help to clarify the role such cues play in the speech of Southerners for listeners, but such a view of these phenomena is out of the scope of this study and left for other work (see, e.g., Gunter, Vaughn, and Kendall 2017). To determine whether vector length and trajectory length, metrics relating to a vowel's dynamicity, are related to participation in the SVS, especially for speakers who have overlapping vowel nuclei, we compare them to Fridland and Kendall's (2012) measure of "Southern shiftedness," the proximity of /e/ and /ɛ/ vowel means as measured by Euclidean distance. Do speakers with closer F1/F2 values for /e/ and /ɛ/ show differences in vector length or trajectory length that would suggest trading cues? We might also suspect that trajectory length would be a better correlate to the SVS than vector length for front lax vowels that exhibit more breaking (Thomas 2001; Koops 2014).

Table 2 shows Pearson correlations between Southern speakers' means for vector length and trajectory length for each of the five front vowels with each speakers' /e/ ~ /ɛ/ Euclidean distance. A strong correlation (i.e., high *r*-value) between our Euclidean distance measure of the SVS with vector length and trajectory length indicates that our dynamic measure increases or decreases as speakers' vowel positions become more affected by the SVS. Though we are using /e/ ~ /ɛ/ Euclidean distance as a proxy for Southern shifting in general, it may be the case that correlations are weaker for other front vowel classes, especially the high front vowels, since many of our speakers primarily show overlap in the /e/ and /ɛ/ vowels, which is in line with Labov, Ash, and Boberg's (2006) findings that the high front vowel reversal is limited to a small geographic area within the South, not represented by our speakers. But the fact that we see correlations for other classes shows that /e/ ~ /ɛ/ Euclidean distance is a reasonable proxy for the SVS in general.

First, these results show that there are significant correlations for each vowel class except /i/. For /e/, we see a significant negative correlation between /e/ ~ /ɛ/ Euclidean distance and both vector length and trajectory

TABLE 2
Vector Length and Trajectory Length Correlations with /e/ ~ /ɛ/ Euclidean Distance

| | *Vector Length* | | *Trajectory Length* | |
|---|---|---|---|---|
| | *r* | *p-value* | *r* | *p-value* |
| /i/ | –0.077 | > .05 | –0.002 | > .05 |
| /ɪ/ | –0.428 | .012 | –0.343 | .047 |
| /e/ | –0.580 | < .001 | –0.548 | .001 |
| /ɛ/ | 0.665 | < .001 | 0.630 | < .001 |
| /æ/ | 0.401 | .019 | 0.413 | .015 |

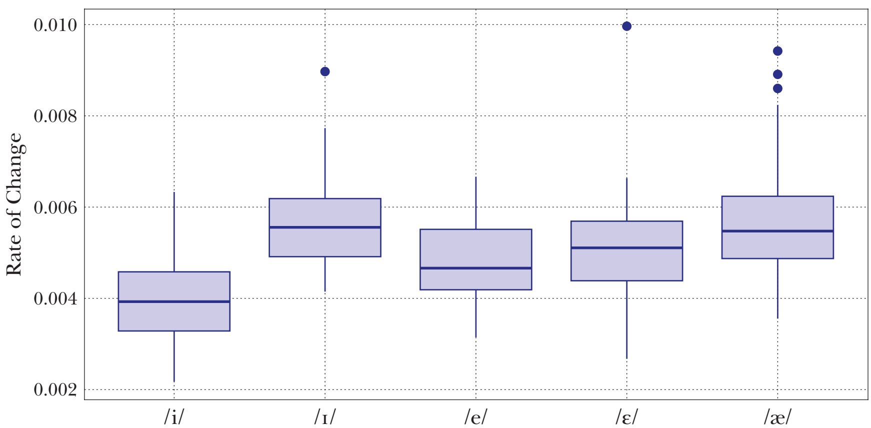
length, meaning that speakers with more proximate /e/ and /ɛ/ vowels (the most shifted SVS speakers) have the longest /e/ vector length and trajectory length. Next, while we might expect the high and mid front lax vowels, /ɪ/ and /ɛ/, to exhibit similar patterns, we see that, in fact, SVS speakers have more dynamic and longer glides for /ɪ/, but shorter, less dynamic glides for /ɛ/. However, this is likely resulting from the fact that the relevant contrasting vowel to /ɛ/ is /e/, so the shorter vector length and trajectory length for the more shifted speakers makes the mid front vowel pairs more distinct dynamically, when exhibiting overlapping nuclei. In earlier work in these data, Fridland, Kendall, and Farrington (2014) found that as spectral means overlap between the vowel classes, the duration also becomes more similar. Thus, vector length and trajectory length might be part of the cue trading relationship that disambiguates the mid front vowels in the SVS. While vector length shows stronger correlations compared to trajectory length for most vowel classes, we observe that the difference between the size of the correlation is slight. The low front vowel, /æ/, shows a significant positive correlation with /e/ ~ /ɛ/ Euclidean distance, and actually has a stronger trajectory length correlation. Like /ɛ/, more shifted SVS speakers have shorter glides for /æ/. This is somewhat unexpected, as we might expect the shifted speakers to exhibit lengthened (and/or triphthongal) /æ/ vowels, but this is not the case.

In summary, to answer our question about how the dynamic measures of vector length and trajectory length relate to the SVS, we asked whether these measures differentiate the South from the West. When collapsing all the Southern speakers together, we lose the intraregional variation of shifted to nonshifted speakers. And thus, we do not find significant differences between the two regions for trajectory length. However, when we look within the Southern region at the relationship of vector length and trajectory length to /e/ ~ /ɛ/ Euclidean distance, our static measure of the SVS, we see strong correlations. This shows that the South uses vowel dynamics in a way that is not captured when aggregating speakers together. And while trajectory length might be a more accurate measure for tracing a vowel's actual trajectory (Fox and Jacewicz 2009), the difference between how vector length and trajectory length correlate with the SVS is negligible. The fact that vector length makes for a slightly better correlation compared to trajectory length suggests that overall glide length is the crucial information, rather than internal (triphthongal) movement.

SPECTRAL RATE OF CHANGE. In addition to looking at how vector length and trajectory length illuminate the relationship among Southern vowels and the SVS, we also want to determine whether temporal information, such as spectral rate of change across the vowel's trajectory, may also be involved in the front vowel shifts in the South. This temporal aspect, or the speed at which the vowel moves in spectral space, is measured by Fox and Jacewicz's (2009) spectral rate of change measure. Spectral rate of change allows us to examine more closely the dynamics of internal vowel movement.

For each vowel class, we ran ANOVAs on the spectral rate of change values to test the influence of region. These yield no significant differences, so we turn our focus to within-region differences, which are displayed in figure 7. Within the South, there is some indication that vowel classes differ in the temporal aspects of their dynamics. Here, we ran an ANOVA comparing spectral rate of change across the different vowel classes, with a post-hoc Tukey HSD (with only $p$-values < .05 shown: $F(4, 165) = 13.56$, $p < .001$; Tukey HSD: /i/ vs. /ɪ/, $p < .001$, /i/ vs. /ɛ/, $p < .001$, /i/ vs. /e/, $p < .01$, /i/ vs. /æ/, $p < .001$, /e/ vs. /æ/, $p = .01$). The primary difference across the classes is the slow spectral rate of change of /i/, which could play a role in differentiating the high front lax and tense vowels. Interestingly, despite differences between the vector lengths and trajectory lengths of /e/ and /ɛ/, the spectral rate of change is not significantly different between them for the South. So, while this kind of temporal measure could indeed contribute reliable cues to vowel identity when other major aspects of vowels (e.g., spectral position) are relatively similar across dialects, this does not appear to be the case for Southern speakers for the mid front vowels. Spectral rate of change is direction independent and might play a secondary role in concert with other cues, as it only appears to play a role in distinguishing the high front tense vowel from other vowels in our Southern sample.

FIGURE 7
Spectral Rate of Change by Vowel Class for Southern Speakers



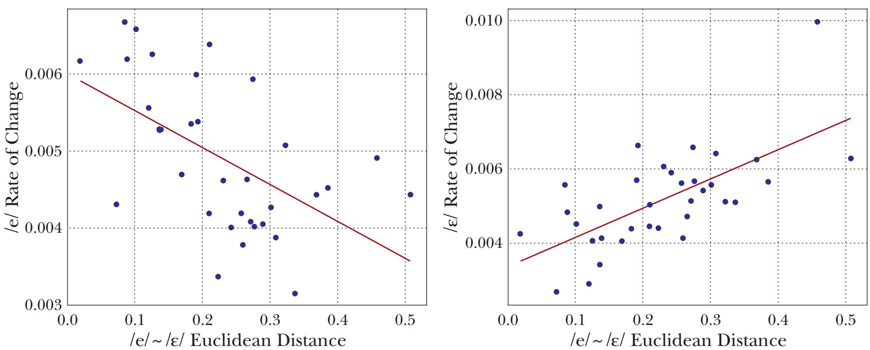
In addition to investigating its potential role as a cue to vowel quality, we are also interested in how our spectral rate of change measure may be linked to participation in the SVS. When we look at the correlations between spectral rate of change and our SVS /e/ ~ /ɛ/ Euclidean distance measure (shown in table 3), significant correlations do occur for the /e/ and /ɛ/, the two vowel classes most strongly affected by the SVS pattern. Figure 8 plots these significant correlations.

For /e/, we find that the most shifted speakers (i.e., those with /e/ ~ /ɛ/ Euclidean distance measures closest to 0) have the fastest spectral rate of change. This is not surprising as the shifted speakers also have the longest trajectories so the frequency change will have to be faster over the same amount of time as nonshifted speakers (see vowel plots in figure 3 for examples of a shifted and nonshifted speaker). With /ɛ/, though, the most shifted speakers have the slowest spectral rate of change. If we recall from above, both vector length and trajectory length for /ɛ/ were shortest for the more shifted speakers. So even while spectral rate of change does not distinguish the /e/ and /ɛ/ vowel classes overall for the South, there is a relationship between spectral

TABLE 3
Spectral Rate of Change Correlations with /e/ ~ /ɛ/ Euclidean Distance

| | *r* | *p-value* |
|---|---|---|
| /i/ | 0.035 | > .05 |
| /ɪ/ | –0.021 | > .05 |
| /e/ | –0.553 | < .001 |
| /ɛ/ | 0.667 | < .001 |
| /æ/ | 0.282 | > .05 |

FIGURE 8
Correlations of /e/ and /ɛ/ Spectral Rates of Change with /e/ ~ /ɛ/ Euclidean Distance



rate of change and spectral position. This suggests another example of a cue trading relationship wherein dynamic properties can help differentiate vowel classes in the SVS.[4]

To summarize, we do not find regional differences in spectral rate of change; in fact, except for /i/, we also do not find vowel class differences. But we do find some significant correlations between spectral rate of change metrics and our SVS /e/ ~ /ɛ/ Euclidean distance measure, especially for the spectral rates of change of /e/ and /ɛ/. The effect of spectral rate of change might be mechanically predicted by other dynamic factors. For example, with /e/, the retraction and lowering of the nucleus results in the lengthening of the glide (increased vector length and trajectory length), while the duration does not increase (Fridland, Kendall, and Farrington 2014). An increase in the amount of frequency change over the same duration would result in an increase in the speed with which the vowel moves over time. So, essentially, for a vowel like /e/ in the SVS, this is an automatic effect of vector length and trajectory length differences. For /ɛ/, this relationship is less clear. The vector length and trajectory length are much shorter for /ɛ/ compared to /e/ (and similar in the high front vowels); the trajectory information might just carry less weight as a cue when there is less spectral movement.

VECTOR ANGLE. Our metrics, thus far, exhibit patterns within the Southern speaker group and in correlation to our SVS measure. These metrics are nondirectional, meaning vector length, trajectory length, and spectral rate of change do not capture any spectral positional information. But we know that other features like formant position and vowel directionality are both important ways to distinguish vowels. In the SVS, for example, front gliding versus ingliding vowels are often described as features of the front vowel system (Fridland 2012). In figure 3, for example, Dustin312 and JonNC03 both show front gliding versus ingliding tense and lax vowels, respectively, as well as longer tense vowel glides. This suggests that the endpoint or target of the glide might vary in sociolinguistically important ways, such as the glide direction of the proximate mid front vowels in the SVS (Labov, Ash, and Boberg 2006; Fridland 2012). Are these differences, especially for /e/ and /ɛ/, captured by vector angle, a quantitative measure of vowel direction? And, does such a measure shed additional light on finer-grained aspects of SVS reflexes?

While we did find that vector length and trajectory length were significantly longer for the /e/ vowel class compared to /ɛ/, the perception of vowel quality would be a combination of those vowel length differences plus where the vowel is traveling in acoustic space. In Southern speech, specifically for the high and mid front vowels, we suggest that directionality is likely one of the cues that distinguish vowels. It would indeed be possible for other varieties that a vector angle measure does not distinguish classes (e.g., languages that have contrastive duration). To demonstrate the vector angle measure, figure 9 provides a hypothetical example showing identical vowel onsets for the /e/ and /ɛ/ vowel classes as well as each vowel having identical vector length and trajectory length measures. In this example, the only difference is in the directionality of the glide, which is upgliding for /e/ and downgliding for /ɛ/.

To our knowledge, vector angle, which we might expect to show differences across the vowel classes, is not something that has been quantified in prior sociophonetic work (but see Fabricius 2008 for work using angle calculations between vowel classes). Figure 10 illustrates a polar coordinate plot of Dustin312's front vowel means as well as his front vowel plot (created using the plotrix package in R; Lemon et al. 2008). (The $r$ and $\theta$ values for the example polar coordinate plot are calculated based on the vowel means plotted in figure 10, not by averaging the angle measures based on individual tokens.) In a polar plot, the vowel onset point is set to a coordinate of $(0, 0)$, and the vectors show the angle of the vowel onset to the vowel offset. For example, a $\theta$ value of $0°$ would be a back-gliding vowel. Such a plot allows us to clearly see differences in glide directionality. For reference, table 4 shows the values of Dustin312's $r$ and $\theta$ polar coordinate values.

FIGURE 9
Hypothetical /e/ ~ /ɛ/ Glide Offset Differences

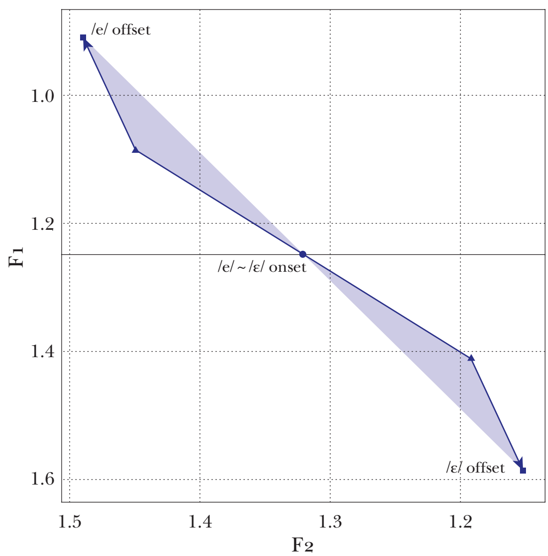


FIGURE 10
Dustin312 Polar Coordinate Plot with Accompanying Front Vowel Plot

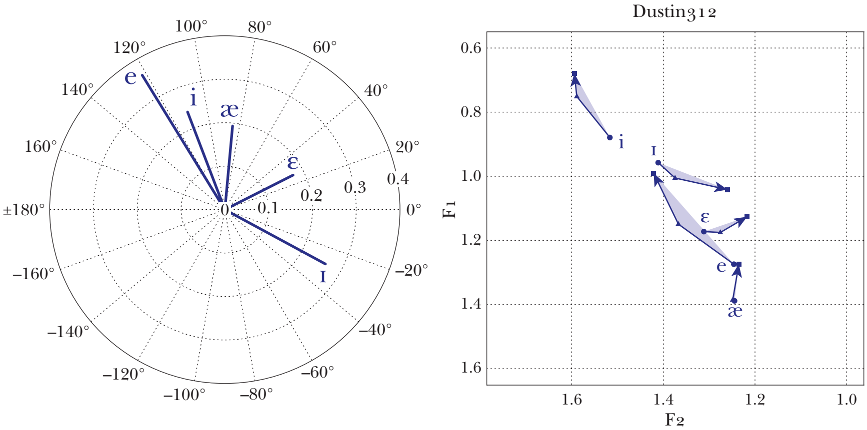



TABLE 4
Dustin312 Front Vowel Polar Coordinates

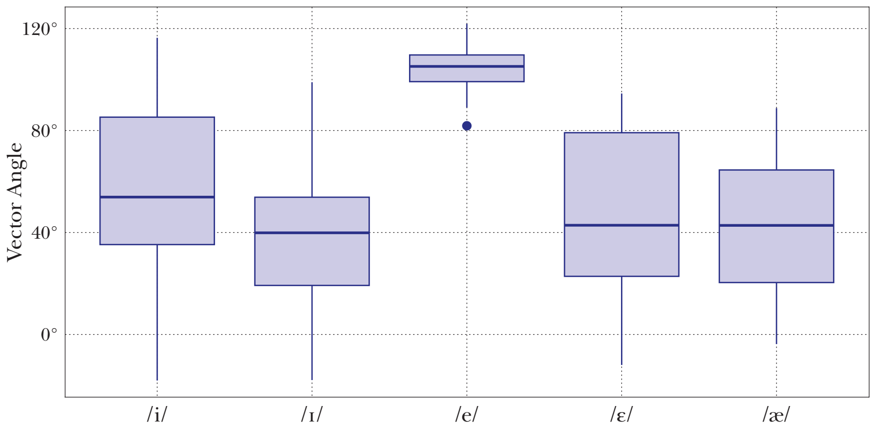
| | $r$ | $\theta$ |
|---|---|---|
| /i/ | 0.233 | 111.18° |
| /ɪ/ | 0.256 | –29.11° |
| /e/ | 0.355 | 121.80° |
| /ɛ/ | 0.168 | 26.40° |
| /æ/ | 0.185 | 84.95° |

In figure 10, we can see that Dustin312's vowels behave, in terms of offglide direction, as we would expect of SVS shifted vowels. For example, his front lax vowels /ɛ/ and /ɪ/ are both ingliding and have values of 26° and –29°, respectively. These strong inglides could help to differentiate these vowel classes from the high front gliding /e/ and /i/.

ANOVAs were computed to test the influence of vowel class on vector angles with a post-hoc Tukey HSD with $p$-values, ($F(4, 165) = 31.08$, $p < .001$; Tukey HSD: /e/ vs. /æ/, $p < .001$, /e/ vs. /ɛ/, $p < .001$, /e/ vs. /i/, $p < .001$, /e/ vs. /ɪ/ , $p < .001$, /i/ vs. /ɪ/, $p = .06$). Figure 11 shows that vector angle clearly differentiates between certain vowel classes.

Essentially, /e/ has the greatest vector angle measure compared to all other vowel classes, with a median value around 105°, which means that it has a high and front-gliding vowel vector. In terms of the front vowel pairs, /e/ and /ɛ/ have significantly different distributions, while we see that the high front vowels approach significance, with /ɪ/ exhibiting vector angle values lower than /i/, which reflects more ingliding. Again, here we see the pattern

FIGURE 11
Vector Angle by Vowel Class for Southern Speakers




of the mid front vowels, those we predict to be most likely affected by the SVS pattern, showing stronger distinctions on dynamic measures. We should also note that all vowel classes expect /e/ tend to be backward gliding, which can be seen for both Southern and Western speakers in figures 11 and 12.

Next, we turn our attention to the vowel measures across regions. ANOVAs were computed on the vector angle measures by vowel class, testing the influence of region on speaker-level means. By itself, vector angle does not appear to play a role in distinguishing regions, as illustrated in

FIGURE 12
Vector Angle by Vowel Class for Southern and Western Speakers

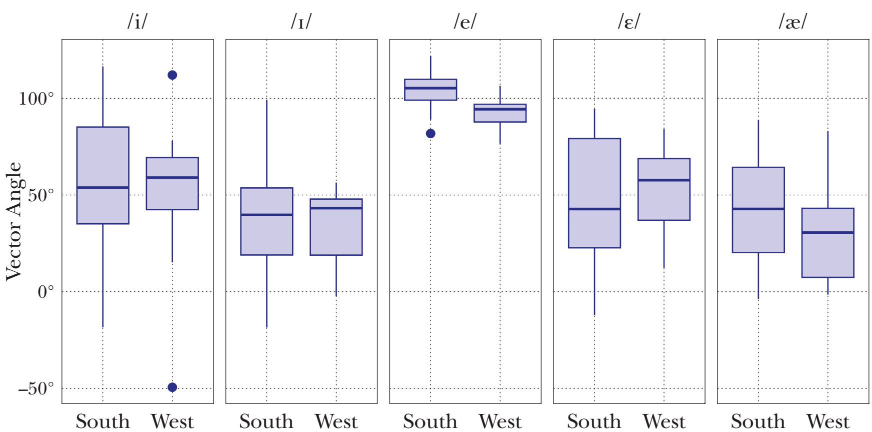


figure 12, with the exception of /e/, which was the only vowel class that yielded significant regional differences. The South exhibited a larger vector angle than the West ($F(1, 40) = 9.968$, $p < .01$). For Southern /e/, a lowered and retracted nucleus results in a more obtuse vector angle, with a similar high front gliding offglide target. The Western /e/ nucleus is in a more cardinal position, and the offglide is upgliding.

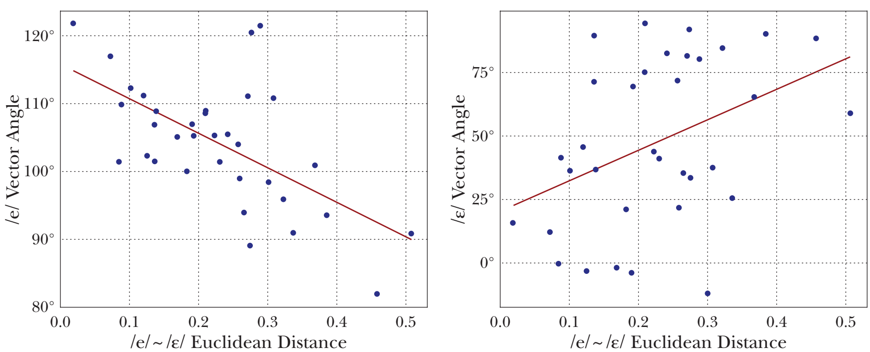
So, to better understand this suspected relationship between the SVS and vowel directionality, we perform Pearson correlations with /e/ ~ /ɛ/ Euclidean distance across the Southern speakers. These correlations are listed in table 5. Similar to our other measures, vector angle obtains the most significant correlations for the mid front vowels, which are also plotted in figure 13.

For /e/, the most shifted speakers have higher vector angles, representing a more obtuse angle, around 120°, while the angle is more upward and less forward, around 100°, for the less shifted speakers. The change in degree for /e/ likely represents the effect of the backing of the /e/ vowel onset for an SVS speaker while maintaining a similar glide target. Again, though, as with vector length and trajectory length, such an additional contrast to a shifted

TABLE 5
VA Correlations with /e/ ~ /ɛ/ ED

| | *r* | *p-value* |
|---|---|---|
| /i/ | –0.296 | > .05 |
| /ɪ/ | 0.258 | > .05 |
| /e/ | –0.606 | < .001 |
| /ɛ/ | 0.403 | < .018 |
| /æ/ | 0.159 | > .05 |

FIGURE 13
Correlations of /e/ and /ɛ/ Vector Angle with /e/ ~ /ɛ/ Euclidean Distance



speaker's /e/ provides an additional cue to vowel quality that is lacking in the nonshifted system. The correlations between /ɪ/ and /ɛ/ are in the same direction, showing that the more shifted speakers have ingliding (and for some speakers, downward ingliding) front lax vowels (see Dustin312's polar coordinate plot in figure 10).

To summarize, for vector angle, our vowel directionality metric, we find that /e/ is the only vowel class where the South patterns significantly differently than the West, and in this case, it is likely related to a lowered and retracted nucleus. Across vowel classes within the South, the vector angle of /e/ is significantly greater than all the other vowel classes. But if we consider this in terms of tense and lax pairs, this exemplifies the different directions of the diphthongal /e/ vowel and the backgliding /ɛ/ vowel. For /i/ and /ɪ/, we find a near significant difference, with /i/ having a higher offglide than /ɪ/. When correlating vector angle to the SVS, the patterns are most prominent for the mid front vowels, with the more shifted speakers exhibiting the greatest differences between the classes. For vowels like /ɪ/ and /æ/, it might be the case that with shorter vector length and trajectory length values, the direction (vector angle) does not matter as much. Further, given that /æ/ is differentiated by spectral position already, there may not need to be a reason for it to be further differentiated by these other cues.

ANALYSIS SUMMARY. Before summarizing our analysis, we want to repeat our research question: to what extent is the SVS characterized by differences that involve dynamics and not just vowel positions? To examine this, we looked at the role of glide dynamics, as measured by vector length (assessing the length of the glide); trajectory length (incorporating a measure of dynamicity within the glide); the speed of frequency change, measured by the spectral rate of change; and vowel glide direction, measured by vector angle, the angle of the vowel glide from the onset position. We then looked at how these measures correlate with a more traditional (F1/F2) measure of SVS participation. In table 6, we summarize our results for each of the front vowels by looking at the regional comparison, the correlation with the SVS measure, and whether the front lax and tense vowel pairs exhibit differences within the Southern speakers. Check marks show whether a positive result was found for each metric. We found marginal differences for /e/ and /ɛ/ when comparing all of our Southern speakers to a sample set of Western speakers, but it must be remembered that our Southern speakers exhibit a range of production systems, from nonshifted to shifted.

When examining individual speakers within the South, we find significant correlations between our dynamic measures vector length, trajectory length, and vector angle and our SVS metric, especially for the mid front vowels,

TABLE 6
Summary of Findings for Vowel Classes

| | *Vowel* | *Vector Length/ Trajectory Length* | *Spectral Rate of Change* | *Vector Angle* |
|---|---|---|---|---|
| Regional comparison (South vs. West) | /i/ | – | – | – |
| | /ɪ/ | – | – | – |
| | /e/ | – | – | ✔ |
| | /ɛ/ | – | – | – |
| | /æ/ | – | – | – |
| Correlation to SVS | /i/ | – | – | – |
| | /ɪ/ | – | – | – |
| | /e/ | ✔ | ✔ | ✔ |
| | /ɛ/ | ✔ | ✔ | ✔ |
| | /æ/ | ✔ | – | – |
| Vowel differences | /i/ vs. /ɪ/ | – | ✔ | – |
| | /e/ vs. /ɛ/ | ✔ | – | ✔ |

meaning that the mid vowels are differentiated from each other on the basis of these vowel dynamics. Since our SVS metric is based on the relative positioning of /e/ and /ɛ/ onsets, there might be reason to expect that aspects of these vowels will correlate more than other vowels. But /e/ ~ /ɛ/ Euclidean distance is not an arbitrary measure, as it has been found to correlate with how Southern sounding an individual is (Fridland and Kendall 2012; Gunter, Vaughn, and Kendall 2017). Additionally, beyond /e/ and /ɛ/, we see some significant results across the other vowels analyzed, including across regions, vowel classes, and in correlation with the SVS /e/ ~ /ɛ/ Euclidean distance. The front vowels in the South are differentiated by cues other than simply F1/F2. As traditional measures of the front vowel lax and tense pairs within the SVS used by sociolinguists often show vowel onsets as similar, it should be clear that spectral position reveals only part of the story. Other cues, like those we analyzed here, reflect different aspects of dynamic vowels, including vowel movement, speed, and direction, which likely plays a role in the perception of vowel classes in the SVS.

## CONCLUSION

The SVS is a dynamic shift that affects different aspects of the vowel classes involved. While it is the case that the SVS is characterizable by single point measures, one goal of this study was to address the relationship and differences between conventional (i.e., static) measures and several measures of dynamic aspects of the front vowels. While F1 and F2 measures have been used, the fact that they overlap for some vowels in the SVS suggests that other cues play important roles in disambiguation of vowels in the South, compared to other regions. More precise measures of vowels beyond single points more accurately reflect the dynamic complexity of actual vowel movement (Fox and Jacewicz 2009) and have been found to reflect other external factors (Van der Harst, Van de Velde, and Van Hout 2014).

So, do the metrics that we looked at add to our understanding of the SVS? From past research on the SVS, and on Southern American English in general, we know that there are dynamic properties in front vowel production that are likely resulting from the SVS (Fridland 2012). Beyond static vowel nucleus position, these properties can involve internal dynamics or the direction that the vowel moves in spectral space. Our research uses a per-speaker /e/ ~ /ɛ/ Euclidean distance measure to represent each speaker's level of involvement in the SVS, following other recent work (Fridland and Kendall 2012; Kendall and Fridland 2012; Gunter, Vaughn, and Kendall 2017), where more-shifted speakers realize a smaller Euclidean distance, and less-shifted speakers have a larger Euclidean distance. We use a series of measures representing different nonstatic aspects of vowels, including vowel length (vector length and trajectory length), speed of vowel frequency change (spectral rate of change), and direction of vowel movement from onset to offset (vector angle).

Since we know that vowels are inherently dynamic, it is possible that some measures, like spectral rate of change, are less reflective of SVS mechanisms and more reflective of vowel production processes in general, but others, like vector length and trajectory length, clearly show that vowel length is correlated to the SVS. For /e/, in static space, we know that more shifted SVS speakers lower and retract the vowel nucleus, but it appears that the glide offset position remains the same, which effectively lengthens the glide. As such, the spectral rate of change increases so that the larger amount of frequency change can occur over the same duration (Fridland, Kendall, and Farrington 2014). Other aspects, like glide direction, are often mentioned in the literature (Labov, Ash, and Boberg 2006; Fridland 2012) but not quantified. In our work, vector angle is implemented as a straightforward way to quantify glide direction, and, as we found here, appears to play a role in disambiguating SVS vowels. This work not only elucidates what measures might be most useful for the study of the SVS, but also adds to our understanding of the SVS and the role that dynamics play in Southern speech, something that is often alluded to in past research but rarely studied.

In essence, the measure that a researcher selects depends on the aim of the research. For example, if we want to look at change over time within the

SVS, it is probably sufficient to continue to use traditional static measures since those measures correlate with several dynamic features. Similarly, any of these measures should show different aspects of change over time depending on the vowel. If we want to describe how to produce a SVS shifted vowel, we need more dynamic measures that reflect more accurately different productions. And if we want to quantify what correlates to folk notions of the drawl, measures that reflect dynamic aspects of vowel production, that is, that which listeners hear, should be integral (even if these measures correlate with single point measures). In fact, the metrics that do correlate with Euclidean distance, do not correlate perfectly, and the ones that do not correlate as well might capture perceptually what speakers still categorize as Southern. We must also look forward and think about how these kinds of specific dynamic measures are related to the perception of Southern speech, which has also been understudied in sociolinguistics. In attempting to capture these dynamics with different kinds of metrics, the goal of this study has been to focus on speech production, but we have noted the role of perception in this article, which is left for follow-up work for now.

Returning to our introductory quote from Ladefoged and Maddieson (1996), who say that speech is an active process and its dynamic aspects need to be examined if we are to more fully understand its properties, we believe that we have, in the current study, underscored this point. Our results support the utility of looking at dynamic measures to better understand how sound change, such as that occurring with the SVS as well as many other varieties, may affect vowels on a number of different levels. As such, it is important to heed recent calls to expand the sociophonetic tool kit beyond single point measures (Wassink 2006; Fox and Jacewicz 2009).

## NOTES

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1. In some varieties of Southern English, /æ/ is slightly raised and might not represent the bottom corner of the vowel envelope. For the current speakers, who do not show this kind of raising, it should not matter much for the current normalization procedure, but future work with other speakers might need to use a different vowel to represent the bottom corner (e.g., the nucleus of prevoiced /aɪ/, which is not as variable for Southern speakers).

2. These plots show the three data points for each vowel class in the analysis. The shaded area for each vowel highlights the difference between the vector length and trajectory length. The middle point for each vowel class is the point that would be plotted in a traditional (midpoint only) plot, and the vector from onset to offset is what would be plotted in a plot with onsets and glides. At least for some vowel classes, like /e/, neither of these views reveals the complete picture.
3. Though we are running multiple correlations with these data that would often call for a Bonferroni corrected *p*-value, our primary focus here and for the rest of the article is not to make strict claims based on statistical significance, but to uncover trends regarding these metrics.
4. In addition to our general measure of spectral rate of change, we also looked at the rate of change more locally within a vowel. To do this, we took the spectral rate of change from the different segments within the duration of the vowel, based on the individual vector components of the trajectory length. The goal of this more localized analysis was to explore the differences in the rate of frequency change in the first half of the vowel duration (20% point to 50% point) compared to the second half of the vowels (50% point to 80% point), corresponding to Koops's (2014) notion of a "delayed initial target" in Southern English vowels, since such a delay could be expected to result in a slower frequency change over the first half of the vowel compared to the second half. For this measure, only high vowels exhibit any type of correlation with our SVS /e/ ~ /ɛ/ Euclidean distance measure, such that the most shifted speakers exhibit faster spectral rates of change in the first half of the vowel for both /i/ and /ɪ/. The pattern, though, is not the one that we would expect, if a delayed initial target means a slowing down of the spectral rate of change. This measure, as pointed out by an anonymous reviewer, might not be salient for a listener, as the landmark of 50% point might not represent an actual target, like the nucleus of a vowel, and just a measurement point for the analyst. While we are not reporting on this measure here, this VOWEL SECTION LENGTH SPECTRAL RATE OF CHANGE metric has been used elsewhere (Fox and Jacewicz 2009) and could be useful in other language varieties if it is expected that there are more local differences in the speed of frequency change.

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