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Anticipatory Coarticulation and Stability of Speech in Typically Fluent Speakers and People Who Stutter

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Anticipatory coarticulation and stability of speech in typically fluent speakers and people who stutter

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Abstract

This project replicates and extends previous work on coarticulation in velar-vowel sequences in English. Coarticulatory data for 46 young adult speakers, 23 who stutter and 23 who do not stutter show coarticulatory patterns in young adults who stutter that are no different from typical young adults. Additionally, the stability of velar-vowel productions is analyzed in token-to-token variability found in multiple repetitions of the same velar-vowel sequence. Across participants, identical patterns of coarticulation were found between people who do and do not stutter, but decreased stability was found in velar closure production in people who stutter. Decreased stability was found in significant subset of people who stutter while others appeared no different than typical speakers. Outcomes of this study suggest that articulatory maturation in young adults who stutter is, on average, no different from typical young adults, but that some young adults who stutter could be viewed as having less stably activated articulatory sub-systems.

1.0 Introduction

This study examines lingual coarticulation and stability of speech using ultrasound imaging of velar-vowel coarticulation in a relatively large sample of adults who do and do not stutter. Coarticulation has been used as a measure of the maturity of cognitive and articulatory processes necessary for fluent speech production (Zharkova, Hewlett, & Hardcastle, 2011; Barbier, Perrier, Menard, Tiede, & Perkell, 2013). Anticipatory coarticulation in velar-vowel sequences provides insight into the mechanisms of speech planning as the tongue dorsum is an active articulator for both the vowel and consonant gestures. Little is known about how lingual speech articulation varies between people who stutter in comparison to typically fluent speakers. Previous research has primarily examined lingual articulation indirectly using formant transitions (Chang, Ohde, & Conture, 2002; Robb & Blomgren, 1997; Sussman, Byrd, & Guitar, 2011), or has examined lip movement (Smith, Sadagopan, Walsh, & Weber-Fox, 2010; Walsh & Smith, 2013). Studies of speech production with children and young adults using ultrasound imaging have found that direct articulatory measures provide insight into lingual articulation and coarticulation that are not revealed through acoustic measures (Zharkova, Hewlett, & Hardcastle, 2012)

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1.1 Stuttering

Stuttering impacts as many as 5.6% of children and persists in slightly less than 1% of adults (Yairi & Ambrose, 2013), with an overall recovery rate of ~67% (Craig, Hancock, Tran, Craig, & Peters, 2002). For some of those individuals, stuttering may negatively impact their ability to achieve in post-secondary education and vocationally (Beilbey, Byrnes, Meagher, & Yaruss, 2013). Adulthood stuttering may also raise social and interpersonal challenges (Yaruss, 2010). Behaviorally, adults with stuttering often (maladaptively) control their environments in order to limit speaking roles and thereby avoid stuttering (Guitar & Belin-Frost, 1998), based on acute awareness of negative public perceptions directed toward them in relation to stuttering. In the speaking roles that adults with stuttering do maintain, they may experience chronic anxiety and struggle and even develop expectancy that social interactions will be harmful (Iverach, O'Brien, Jones, Block, Lincoln, Harrison, & Onslow, 2009). At the very least, adults with stuttering may feel dissatisfaction with their quality of life in relation to stuttering (Altholz & Golensky, 2004). These factors underscore the need for continued understanding of mechanisms contributing to stuttering and refinement of interventions for adulthood stuttering.

Fluent speech production is driven by both efficient language production (Levelt, Roelofs & Meyer, 1999) and efficient motor speech production (Katz & Bharadwaj, 2001). Recent evidence suggests people who stutter may differ in the psycholinguistic stages of speech plan assembly (Maxfield, Pizon-Moore, Frisch, & Constantine, 2012; Brocklehurst, Lickley, & Corley, 2013). Speech physiological data suggest that people who stutter may also have differences in the initiation, coordination, and control of speech movements. Some of these differences have been observed in tasks testing movement stability and strength of coordinative patterns (Namasivayam & van Lieshout, 2011). According to Max, Guenther, Gracco, Ghosh, & Wallace (2004), moments of stuttering can result when speech is produced using unstable or insufficiently-activated internal models, or when a movement strategy is used that is weighted too heavily toward afferent feedback control of speech production. The possibility that adults who stutter produce speech that is unstably formed or have inadequately activated internal models is the focus of the current study.

Previous research on coarticulation and the speech motor stability of people who stutter has mainly been accomplished by recording of acoustic measures and analysis of formants, some with accompanying video recordings used to identify moments of stuttering (Robb & Blomgren, 1997; Chang, Ohde & Conture, 2002; Sussman, Byrd & Guitar, 2011) with conflicting results. However, studies that rely on the analysis of formant transitions should be interpreted with caution, especially when the overlap of speech articulation is of interest (Löfqvist & Gracco, 1994) and specifically for populations with immature or disordered patterns of speech (Zharkova et al., 2012).

Much of the recent articulatory research in people who stutter has examined lip and jaw kinematics in adults and children with and without stuttering (Smith et al, 2010; Walsh & Smith, 2013). These studies have used word, sentence, and nonword repetition and investigated effects of complexity on articulatory performance. People who stutter were as successful as typical speakers when these tasks were examined behaviorally, such as with error rate and even disfluency (Smith et al, 2010). At the level of articulatory detail, however, there were measurable differences. Both children and adults who stutter were found to have overall greater variability (less stability) in their articulation compared to their typical peers.

A detailed understanding of the articulatory patterns of people with stuttering may lead to a speech motor diagnostic that could be used with children who stutter to reveal differences between those likely to persist in stuttering versus those likely to recover naturally (Smith, et al., 2010; Walsh & Smith, 2013). In addition, investigating anticipatory coarticulation provides implications for treatment planning. Clinically, if significant discrepancies in patterns of coarticulation exist between typically fluent and stuttering groups, then differences at a cognitive-linguistic level are implied, providing indication for a more phonologically-based treatment. In this case, intervention would aim to strengthen organization of phonological representations in speakers with less mature articulatory abilities. If a similar degree of coarticulation is observed between speaker groups, then a sensory-motor based framework may be more appropriate for targeting aspects of speech production. Here, intervention would emphasize articulatory practice, utilizing an intensive service delivery model based on theories that "principles of speech motor learning parallel those of motor learning in general" (Maasen Kent, Peters, van Lieshout, & Hulstijn, 2004, p. 19).

1.2 Coarticulation and Speech Motor Planning

Fluent speech requires context-dependent coordination of multiple speech articulators (Katz & Bharadwaj, 2001). Coarticulation, or the overlapping of sounds in speech, results in measureable differences when sounds are examined in differing surrounding contexts (Zharkova & Hewlett, 2009). Studies of anticipatory coarticulation provide insight into the units involved in speech planning and the extent of "look ahead" in the speech planning process (Benguerel & Cowan, 1974; Nittrouer, Studdert-Kennedy, & Neely, 1996; Recasens, 2002). Anticipatory coarticulation is necessarily an active, higher-level process in speech planning, as different patterns of coarticulation are observed across different languages (Keating & Lahiri, 1993). The current study specifically examines anticipatory velar-vowel coarticulation in the adjustment of velar closure location for /k/ depending on the following vowel context as means of investigating lingual speech motor planning, programming, and production.

The current literature on speech production suggests that there is a developmental progression in speech planning and production that can be indexed by coarticulatory measures (Nittrouer et al., 1996; Goodell & Studdert-Kennedy, 1993; Sussman, Duder, Dalston, & Cacciatore, 1999). It has been suggested that children utilize larger, less specified linguistic units (Kent, Adams, & Turner, 1996). Findings support a progression from syllabic to segmental units, as evidenced by reduced amounts of observed CV coarticulation with increasing age (Nittrouer et al., 1996), though this progression may not be uniform across all segments types or contexts (Sussman et al., 1999). In this view, through a process of refinement of articulatory organization and improvement in coordination of segmental level articulatory gestures, adult speakers display less coarticulated patterns of speech production as compared to children.

Contrary to this pattern, Zharkova et al. (2012) found that certain vowel environments exert significant coarticulatory influences on /s/ productions in adults but not in children using ultrasound imaging of the tongue. They also found that children exhibit greater within-speaker variability in the extent of coarticulation. In the case of Zharkova's study, coarticulation in /s/-vowel productions involved the use of the tongue as two distinct articulators (blade and dorsum) which may require more sophisticated articulatory abilities.

As previous findings on velar-vowel coarticulation suggest, tongue body position for velar closure location is determined to an extent by phonetic context (Keating & Lahiri, 1993). An electromagnetic articulometry study of velar-vowel coarticulation found a progression along the horizontal plane in velar closure location, with velar frontness varying across the vowel contexts /u/, /a/, and /i/ (Löfqvist & Gracco, 1994). It has been concluded in similar ultrasound investigations that velar closure locations fall along a range of locations from front to back along the palate depending on the frontness of the vowel context (Wodzinski & Frisch, 2006). In contrast to /s/-vowel combinations, /k/-vowel combinations require the use of the tongue dorsum for both consonant closure and vowel placement. Thus, the developmental trajectory of anticipatory coarticulation in /k/-vowel combinations may be from greater degrees of coarticulation in children to lesser degrees of coarticulation in adults due to differences in the degree of articulatory constraint for the tongue dorsum (Recasens, Dolor Pallarés, & Fontdevila, 1997).

Figure 1 shows two ultrasound images of the tongue during the production of the velar stops in *key* and *cough*. In this image, the tongue tip is to the right. Figure 1a shows the velar constriction before /i/, a front vowel, in *key* while figure 1b shows the velar before /ɔ/, a back vowel, in *cough*. The forward (rightward) shift of the tongue body in Figure 1a versus 1b is apparent. Presumably, this shift in position occurs because of anticipatory coarticulation between the production of the velar stop and the following vowel.

1.3 Speech Stability and Token-to-Token Variability

In addition to examining coarticulation, the present study introduces a measure of speech motor control, or stability of speech, through examining similarity between tongue postures across multiple repetitions of the velar-vowel sequence. Repetitions were obtained concurrently with the coarticulatory measure, as it has been concluded that, "stable coarticulation is indicative of mature control of articulators during speaking" (Zharkova, et al, 2012 p.118). Previous research has suggested that adults who stutter are less stable even in their fluent productions as compared to typically fluent speakers. Smith et al (2010) found adults who stutter to perform less consistently on repeated inter-articulatory coordinative measures of production and had significant differences in coordinative consistency with increasing phonological complexity. In typically fluent speakers, the majority of studies focusing on within speaker token-to-token measures have identified speech articulation to be more variable in children, with stability increasing with age (Kent & Forner, 1980, Nittrouer, 1993; Nittrouer, Estee, Lowenstein, & Smith, 2005).

If speech motor stability follows a developmental sequence across the lifespan, treatment involving speech motor practice should improve stability over time. Rationale for this treatment recommendation is derived from motor theories at large, which have shown performance accuracy is improved by practice (Kelso & Norman, 1978; Sharkey & Folkins, 1985). Walsh, Smith, and Weber-Fox (2006) demonstrated evidence of short-term effects attributable to practice in speech motor coordination of 10 year old children.

1.4 Summary and Research Questions

Research on speech motor ability is essential for gaining a comprehensive understanding of the complexities of speech production in people who stutter (Max et al, 2014). The present study examines both degree of coarticulation as a measure of higher order planning in the speech production process and stability in the execution of these planned gestural sequences. Combining these two measures will provide insight into two different aspects of the speech production system in people who stutter (Brocklehurst, Lickley, & Corley, 2013). It has been suggested that people who stutter possess more limited speech motor skills, with "less efficient and less flexible adaptation to lower motor and higher cognitive-linguistic order requirements that impact speech motor functioning" compared to typically fluent speakers (Namasivayam & van Lieshout, 2011, p.477). In the case of anticipatory coarticulation for /k/-vowel sequences, producing velar closure in the same location along the palate regardless of vowel context would require adaptation of the /k/ closure gesture to account for advancement of the vowel. An articulatory simplification would be to produce /k/ closure through dorsum raising regardless of vowel advancement, resulting in a wide variety of closure locations. This holistic CV gesture would result in greater variability in the measure of velar closure location in /k/-vowel sequences across vowel contexts. Differences in speech stability between speaker groups may be observed in the variability production of the velar closure with the same vowel context, reflecting either instability in the articulatory strategy that is used or less accurate motor execution of the planned gesture.

2.0 Methods

2.1 Participants

46 speakers participated in a read speech production task: 23 who stutter (19 male and 4 female) and 23 who are typically fluent (12 male and 11 female). The typically fluent group was balanced for gender in order to create a normative sample for young adults. The participant groups were not balanced for gender as stuttering is more prevalent in males. All participants were between the ages of 18–29 and reported American English to be their first language. Typically fluent speakers reported no history of speech, language, or hearing disorders. The people who stutter all self-reported a history of developmental stuttering with no other speech, language, or hearing disorders. The presence of stuttering was confirmed by the second author.

2.2 Stimuli

18 monosyllabic (CVC or CV) words embedded in a carrier phrase were presented one at a time through a computer-displayed script. All target words were provided on a paper list to familiarize participants with the word list before the experiment began. The stimuli consisted of the initial velar stop /k/ followed by one of nine Standard American English vowels: /i e æ ʌ ɝ ɑ ɔ o u/ following Wodzinski and Frisch (2006). These vowels provide a range of degrees of English vowel advancement, front-to-back. Each vowel was used in two different

words presented in a pseudo-randomized order. Identical vowel contexts were not repeated in adjacent stimuli. In the case of CVC words, the coda was a bilabial (/p/ or /b/), or labiodental (/f/ or /v). Labial codas were used to eliminate the influence of additional lingual coarticulation within words (Pouplier & Goldstein, 2005). The word stimuli were: /i/ *key, keep*, /e/ *cay, cape*, /æ/ *cap, cab*, /ʌ/ *cup, cub*, /ɝ/ *curb, curve*, /ɑ/ *cop, cob*, /ɔ/ *caw, cough*, /o/ *cope, cove*, /u/ *coo, coop*. Word stimuli were produced in the phonetically neutral carrier phrase: *Say a ____ again*, which provides a stable coarticulatory environment between schwa vowels and aims for optimal imaging of the onset velar closure. Each stimulus phrase was produced three times in a row, for a total of 6 productions of /k/ for each vowel context across the experiment. Three repetitions per trial were used to avoid differential practice effects between typical adults and adults who stutter over larger numbers of repetitions (Smith, et al, 2010).

2.3 Procedure

The stimulus script was displayed one line at a time on a computer monitor screen, using Articulate Assistant Advanced, 2.0 software (Articulate Instruments, 2007). The participant was seated in a rigid chair in front of the computer screen. Participants wore an adjustable head stabilization unit designed by Articulate Instruments for the purpose of holding the ultrasound transducer beneath the chin (Articulate Instruments, 2008). The ultrasound transducer was adjusted before recording for a midsagittal view centered on the tongue body. An Aloka SSD1000 with 90 degree convex probe was used to generate the midsagittal ultrasound image.

To control their rate of speech, participants wore a digital metronome over their ear that provided a target tempo of 90 BPM. A microphone placed in front of the participant was connected through the synchronization unit, Sync BrightUp, to simultaneously record ultrasound video and acoustic data with a synchronization marker in the audio and video. Phrases were presented in a single fixed order across all participants. Participants read each stimulus phrase three times in a row to the pace of the metronome.

2.4 Measurement

Frames from the ultrasound recording displaying maximum velar closure were identified manually following the procedures of Wodzinski & Frisch (2006), looking for change in tongue movement from raising to lowering across frames, maximum tongue dorsum elevation, and clarity of the tongue dorsum image reflecting a stable point of velar contact. For each velar vowel production a spline was semi-automatically fit to the midsagittal tongue trace on the ultrasound image. Articulate Assistant Advanced generates a spline through a fixed fan of 42 measurement angles from the virtual probe center. Although these splines contained points along the tongue and area of velar closure necessary for comparative analysis, the full spline as generated included points beyond the extent of the tongue's sagittal length due to shadows created by the hyoid bone and visible sublingual space when using a 90 degree probe. Each spline was manually trimmed to the extent of the visible midsagittal tongue with reference to the tongue edge confidence measure automatically provided by Articulate Assistant Advanced.

Differences between tokens were measured using the curve-to-curve distance comparison, following Zharkova and Hewlett (2009). In this measure, an average nearest neighbor point-to-point distance is computed for each pair of curves. For each point on one spline, the nearest neighbor on another spline is located. The distance between each point and its nearest neighbor is averaged across all points in the spline to produce an overall curve-to-curve distance between the splines for two tokens.

To account for across-speaker differences in vocal tract size, the data were normalized by height of velar stop closure across participants as a proxy for vocal tract size. For each token the greatest y-axis value in the spline was extracted. For each participant, the average value across all tokens was used as a normalizing coefficient for that participant as compared to the average across all participants.

3.0 Results

Figure 2 shows tongue images at the point of maximum velar closure for each of the 9 vowel contexts for one fluent young adult speaker. Figure 3 shows average tongue contours for each context as generated by Articulate Assistant Advanced that shows a clear shift from posterior to anterior allophones of the velar stop. This pattern is consistent with the findings of Wodzinski & Frisch (2006) for 10 typical speakers.

Anticipatory velar-vowel coarticulation can be measured by curve-to-curve distance between tokens produced in different vowel contexts. Table 1 shows the grand average curve-to-curve distance for all typical participants between vowel contexts. Note that the curve-to-curve distance measure is not symmetric between two curves (Zharkova & Hewlett, 2009) and so values for both directions of comparison are included in the table. The directional differences are minimal, about 0.1mm on average. The highlight in table 1 shows cells where the mean difference is greater than 3.0mm, the overall grand average across all data. Table 2 shows the same data calculation for the young adults who stutter including highlights at the same cutoff value. Based on the data in tables 1 and 2, further analyses of coarticulation were conducted between the broadly distinct allophonic groups of front (/i, e, æ/) vs. non-front contexts. The average extent of coarticulatory influence was determined within each individual as a mean distance in millimeters between tokens of different-context curves between the front and non-front contexts, normalized for tongue body height. Note that the coarticulation measure shows the status of /u/ as a back vowel is somewhat questionable in this data as the curve distance measure between /u/ and the front vowels is generally lower than what is found for the other non-front vowels. This likely reflects the process of /u/ fronting taking place in several varieties of American English (Clopper, Pisoni, & deJong, 2005).

For speech stability, average curve-to-curve distance was obtained for tokens with the same vowel context (e.g., a speaker's tokens of /ki/ compared to the speaker's other tokens of /ki/). This average distance between curves within the same vowel context can be interpreted as a measure of speech motor stability (or variability) for individual speaker's productions of the appropriate context-dependent velar stop. In order to most meaningfully compare the measure of speech stability for a velar-vowel combination with the measure of coarticulation, same vowel context tokens were compared between the two different words used for each vowel context in the study (e.g. *key* versus *keep*), which may introduce confounding factors into the measure of stability due to long distance coarticulation or drift in ultrasound probe placement over the experimental session. However, the coarticulation measure necessarily uses different word contexts, which also means the coarticulation measure is potentially subject to long distance coarticulation effects and based on productions throughout the experimental session. The analysis of stability was repeated considering all tokens in the same vowel context regardless of stimulus word and the results are identical.

Figure 4 shows mean coarticulation measures (curve-to-curve distances between front and back vowel contexts) and mean stability measures (curve-to-curve distance between words with the same vowel context) across people who stutter and typically fluent speakers after data trimming and normalization. Error bars reflect one standard deviation. Replicating Zharkova et al. (2012) there is a clearly larger between context measure compared to the within context measure, supporting the use of curve-to-curve distance as a measure of coarticulation. Between the speaker groups, there is almost no difference in the between context measure of coarticulation (mean difference 0.04 mm). The within context measure of stability, however, shows significant group differences in both mean measure and variability. An F-test for equality of two variances finds a significant difference between groups ($F(22) = 0.15$, $p < .001$) and a t-test for mean differences assuming unequal variances finds that people who stutter are significantly less stable than typical speakers ($t(30) = 2.0$, $p < .05$). The typically fluent speakers are more stable and less variable in speech stability across participants than the young adults with stuttering.

Following Smith, et al (2010), patterns within the individual speakers within groups were also analyzed. Positive correlations for the coarticulation and stability measures were found in both groups, but with a statistically significant correlation only for the young adults who stutter ($r(21) = 0.48$, $p < .05$), and not for the typically fluent young adults ($r(21) = 0.14$, n.s.). In order to further explore individual differences in among participants, measures for coarticulation and stability are plotted for the individuals in figure 5. In addition to the individual data, a dashed line is included in figure 5 to highlight the stability threshold that is more than 2 standard deviations above the mean in stability for the typically young adults. There is one typical young adult speaker over this threshold (which is roughly as expected for a sample of 23 speakers). Seven young adults who stutter have speech stability scores above the 2 SD cutoff for typical young adults.

4.0 Discussion

In the present study, ultrasound was used to investigate anticipatory velar-vowel coarticulation in the productions of 46 speakers including those who stutter. Previous literature has not addressed speech motor stability and lingual coarticulation using articulatory measures in typical and disordered populations with a large enough sample to establish normative performance (Kühnert & Nolan, 2006). Together with the findings of Smith et al. (2010), who examined lip kinematics in 34 young adults including those who stutter, some general conclusions can be drawn about coarticulation and speech motor stability in young adults who stutter.

The present study found that people who stutter do not differ significantly from typically fluent peers in the production of coarticulation in front versus non-front velar-vowel contexts. Similarly, behavioral measures of speech production in Smith et al. (2010) found no significant differences between young adults who do and do not stutter. This is also consistent with the acoustic study of anticipatory coarticulation in Sussman, Byrd, and Guitar (2011). Since people who stutter performed similarly to typical fluent speakers on the measure of anticipatory coarticulation, it can be assumed disfluencies are not attributable to immature motor planning as measured by anticipatory coarticulation (Zharkova, et al, 2012). However people who stutter were found to be more variable in articulatory measures of their productions of the same velar-vowel target across different words in the present study. Smith et al (2010) found increased variability in lip aperture across tokens in nonword stimuli in people who stutter versus typically developing speakers. As they stand, these findings are consistent with claims that people with stuttering “may be located more toward the unskilled end of a presumed (normal) speech motor skill continuum” (Namasivayam & van Lieshout, 2011 p.477). These findings can also be straightforwardly interpreted in the model of Max et al. (2004). Instability in the articulatory patterns of young adults with stuttering may be a physical manifestation of unstable or insufficiently-activated gestural models of anticipatory coarticulation in velar-vowel sequences.

It may be that some people who stutter limit their speech interactions in order to avoid stuttering, leading to a reduction in lifetime experience with speech (Guitar & Belin-Frost, 1998). In the sample of young adults who stutter in the present study, 7 of 23 had stability measures greater than 2 SD above the mean for the typical speakers (outside of the 95% confidence interval), and 10 of 23 had stability measures greater than 1 SD above the mean for the typical speakers. This suggests that a subset of young adults who stutter have significantly impaired speech stability compared to typical young adults (cf. Smith, et al, 2010). While the young adults who stutter were no different in coarticulation, on average, than the typical young adults, there was a correlation between the stability measure and the coarticulation measure for the stuttering group. To the extent that coarticulation provides an index of articulatory maturity, there may be a subset of stutterers with less developed articulatory abilities. Clinically, their speech stability issues may be amenable to a “practice leads to refinement” approach to therapy. As this example shows, an improved model of speech production and a better understanding of the maturation trajectory in anticipatory velar-vowel coarticulation would be advantageous scientifically and clinically to provide framework for typical and disordered speech production abilities and guide intervention appropriately (Brocklehurst, Lickley, & Corley, 2013).

The target phoneme in this study was /k/, which is known to have relatively large variation in production across contexts. Presumably, studies of other cases of coarticulation with quantitatively smaller degrees of coarticulatory variation are unlikely to find significant differences in anticipatory coarticulation between people with stuttering and typically fluent speakers. However, the present study contrasts with other ultrasound work, such as Zharkova, et al (2012) in that the tongue dorsum is an active articulator in the production of a velar stop (cf. Recasens, Dolor Pallarés, & Fontdevila, 1997). Different coarticulatory patterns may be observed, for example, in /s/+vowel combinations in people who stutter where the tongue body is a relatively unconstrained articulator during consonant production.

Finally, the results of the present study describe the speech production patterns of people who stutter when their speech was rate controlled to be synchronized with a metronome signal. Generally, speech to a metronome should be more fluent and stable than unconstrained speech (Hannah & Morris, 1977) and so the significant differences found here point toward a relatively large difference in speech variability in a subset of the people who stutter. While articulatory measurement of unconstrained speech is more challenging, the development of an articulatory battery with productions in a wide variety of contexts will likely provide additional insights into the variety of speech production process inefficiencies in people who stutter. There are a variety of broader contextual adjustments in the production of speech sounds due to segmental context, prosody, and speech rate. Further, articulatory processes in natural speech take place in coordination with a variety of other cognitive processes to generate utterances and participate in a communicative exchange. The presence of disfluency or instability in articulation across these different situations may be correlated within individuals, or it may be that differential diagnoses of sources of disfluency can be developed if speakers show signs, for example, of speech instability in some situations but not others.

5.0 Conclusion

The present study replicates and extends previous work on coarticulation in velar-vowel sequences in English and finds that 23 young adult speakers who stutter are no different, on average, in velar-vowel coarticulatory patterns compared to typical young adults. However, in speech stability and overall variability, a subset of young adults who stutter are found to be less stable and more variable than typical speakers even in this relatively simple speech task. A correlation between coarticulatory behavior and speech stability suggests that maturation may partially explain differences in the speech motor ability of young adults who stutter, at least for some individuals, and these individuals may benefit from a therapy program using intensive articulation practice to develop their segmental articulatory representations.

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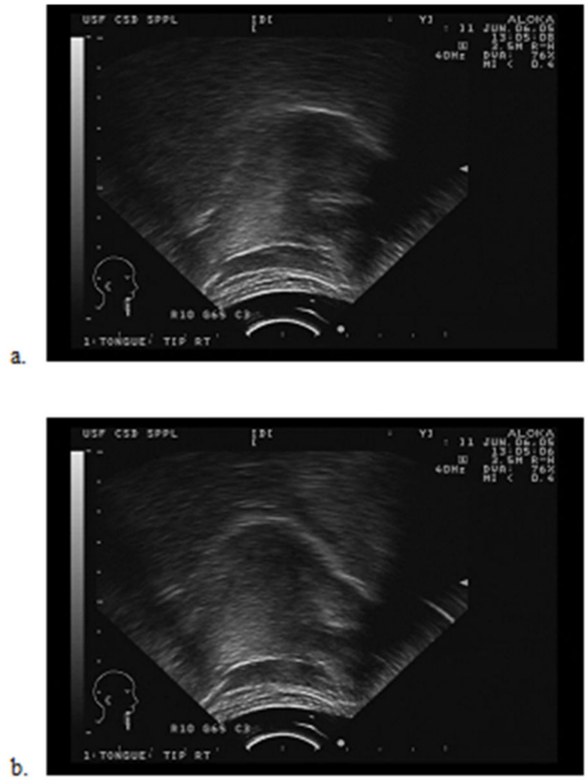

Figure 1.

Ultrasound images with tongue tip to the right showing velar fronting before /i/ in *key* (top) versus /ɔ/ in *cough* (bottom)

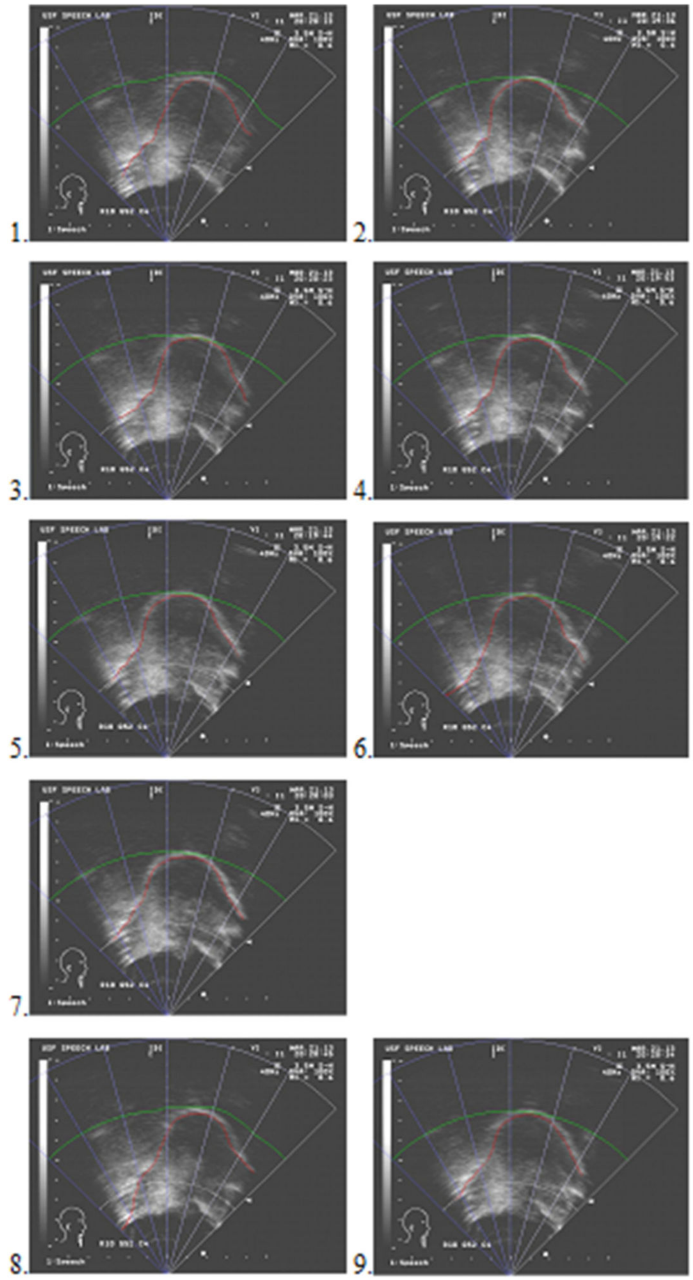

Figure 2.

Ultrasound images with tongue tip to the right depicting a typically fluent young adult's velar closure for /k/ in nine vowel contexts. Target words produced as follows: *1) key, 2) coop, 3) cape, 4) cope, 5) cup, 6) curve, 7) cough, 8) cap, 9) cop.*

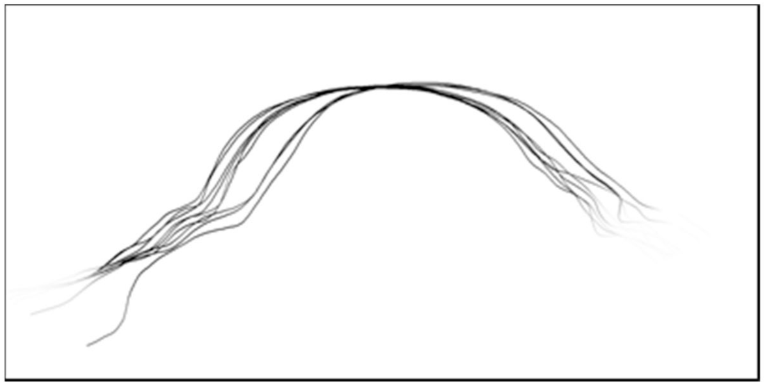

Figure 3.
Mean spline contours (tongue tip to the right) from a typically fluent speaker generated by Articulate Assistant Advanced representing the speaker’s average velar closure location by vowel context

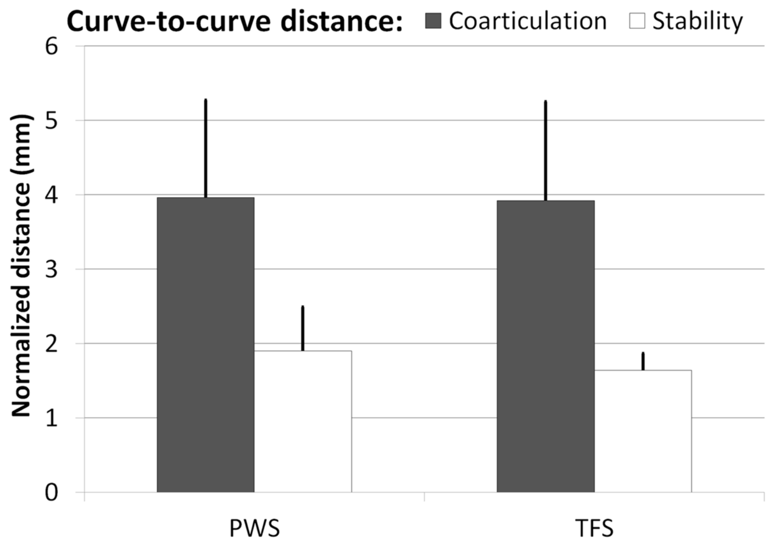

Figure 4.

Average measures for between-context (extent of coarticulation due to front-back vowel context), and within-context (speech stability within same vowel context repetitions of different words) for 23 young adults who stutter and 23 typically fluent young adults. Error bars show standard deviation across participants

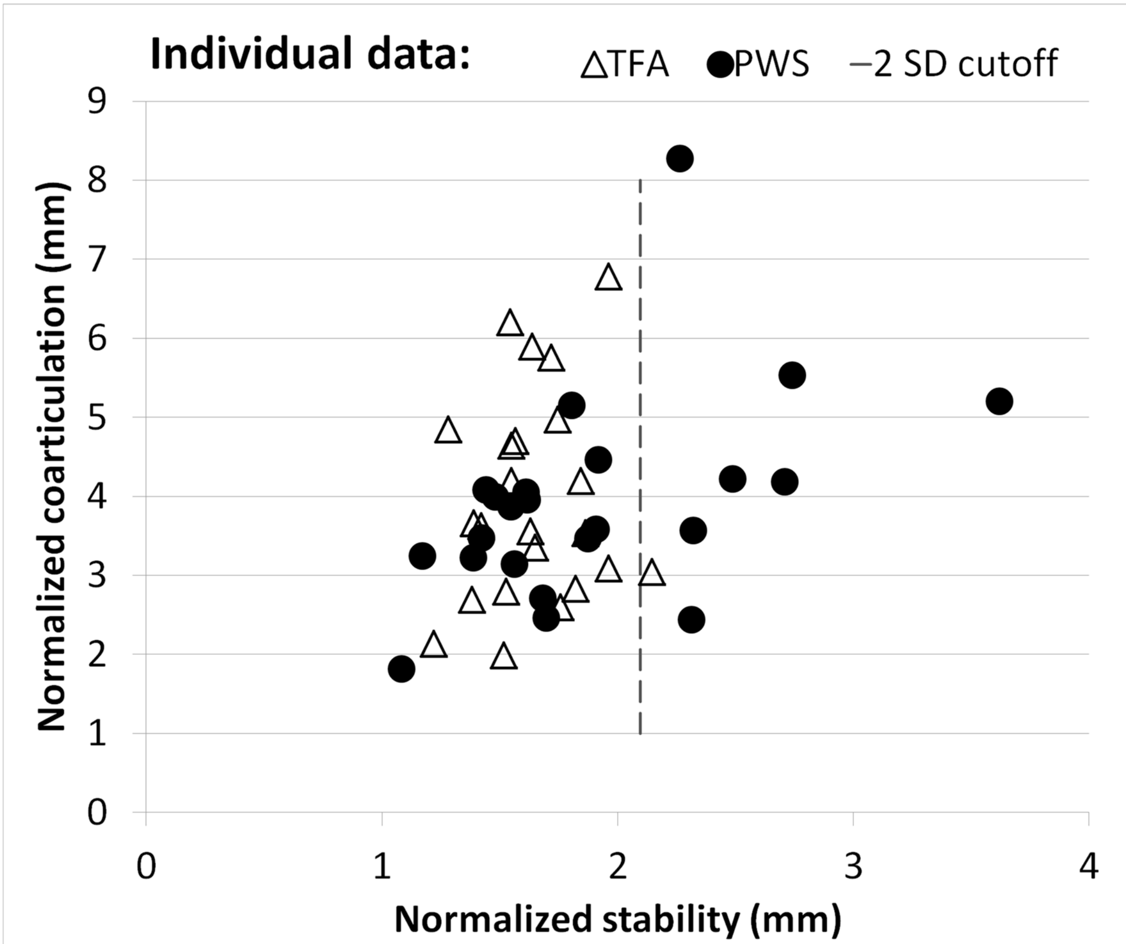

Figure 5.

Individual data for curve-to-curve distance between front-back contexts (coarticulation) and between words in the same vowel context (stability) for 23 young adults who stutter and 23 typically fluent young adults.

Table 1

Grand average curve-to-curve distance (mm) between vowel contexts for typically fluent young adults. Gray shading indicates distance above the overall mean (3.0 mm).

	ki	**ke**	**kæ**	**kʌ**	**kɝ**	**kɑ**	**ko**	**kɔ**	**ku**
ki		1.8	2.3	4.5	4.1	4.8	4.8	5.3	3.3
ke	2.0		1.9	3.8	3.4	4.1	4.1	4.6	2.7
kæ	2.4	1.7		3.3	2.9	3.5	3.5	4.0	2.4
kʌ	4.8	3.9	3.6		2.0	1.7	1.7	1.9	2.4
kɝ	4.4	3.5	3.1	1.9		2.0	2.0	2.3	2.2
kɑ	5.0	4.2	3.8	1.7	2.1		1.8	1.7	2.7
ko	4.9	4.1	3.7	1.6	2.0	1.7		1.9	2.5
kɔ	5.6	4.7	4.3	2.0	2.4	1.7	2.1		3.2
ku	3.6	2.7	2.6	2.3	2.1	2.5	2.5	2.9	

Table 2

Grand average curve-to-curve distance (mm) between vowel contexts for 23 young adults who stutter. Gray shading indicates distance above the overall mean (3.0 mm).

	ki	**ke**	**kæ**	**kʌ**	**kɝ**	**kɑ**	**ko**	**kɔ**	**ku**
ki		1.9	2.6	4.6	4.0	4.7	4.5	4.9	4.1
ke	2.0		1.9	3.8	3.2	3.8	3.7	4.0	3.2
kæ	2.6	1.9		3.3	2.8	3.4	3.2	3.6	2.8
kʌ	4.8	3.9	3.4		2.1	1.9	1.8	1.9	2.0
kɝ	4.1	3.3	2.9	2.0		2.2	2.1	2.2	2.1
kɑ	4.9	3.9	3.5	2.0	2.3		2.0	2.0	2.4
ko	4.7	3.8	3.5	1.9	2.2	2.1		2.0	2.0
kɔ	5.1	4.1	3.7	1.9	2.2	1.9	1.9		2.3
ku	4.2	3.4	3.0	2.1	2.2	2.4	1.9	2.4	