INTRODUCTION

A commonly held view is that stuttering moments are the perceptual consequence of unstable speech motor patterns. Some have argued that this motor instability may arise from a variety of neural sources that interact in a dynamic fashion (Smith, 1999). There does appear to be some growing support for such a perspective. For example, recent studies have demonstrated that under certain conditions, persons who stutter (PWS) tend to exhibit greater <u>utterance-level</u> spatial-temporal variability in the lip movement histories as compared to normally fluent speakers (Kleinow & Smith, 2000). Furthermore, linguistic and speech motor complexity appears to differentially affect motor stability in PWS (Kleinow & Smith, 2000; Smith & Kleinow, 2000). Recently, Howell et al. (2009) described a method for estimating utterance-level variability within the acoustic domain and also found elevated utterance-level variability in PWS. There continues to be a number of issues that have not yet been resolved. First, since these studies have focused on utterance-level variability (see Namasivayam et al. (2009) for an exception), it is unclear if speech motor variability is distributed uniformly across the utterance or whether there are regions where greater variability is more likely. For example, one might predict that motor instability will be most notable where stuttering is frequently observed, such as at utterance onset. Second, most studies have targeted readily available orofacial structures (e.g. lips). It is not known if such findings generalize to other oral articulatory structures such as the tongue and other speech motor subsystems such as the chest wall. To these ends, the current study evaluates spatial-temporal variability of chest wall and oral articulatory structures just prior to and following utterance onset in the fluent speech of persons who do and do not stutter.

METHODS

Participants

- 52 adults drawn from the Walter Reed Army Medical Center-Western Michigan University Stuttering Database

    - 26 persons who stutter (PWS) (25 M, 1 F)

        - Mean SSI-3 score: 25.2 (SSI-3 not available for one participant)
        - SSI-3 range: 10–37

   - 26 normally fluent speakers (NFS) (26 M)

Experimental Task

- All data based on 5 perceptually fluent productions of the the sentence **"She had your dark suit in greasy wash water all year"** spoken at comfortable rate and loudness.

Data Acquisition (See Figure)

- All participants underwent an identical data collection which involved synchronous recording of oral articulatory fleshpoints with electromagnetic articulography, chest wall motion using Respitrace and speech acoustics.

- Experimental task was part of a larger speech sample collection.

Data Acquisition

AG100 Articulograph
- Helmet
- Sensors

Microphone

Respitrace
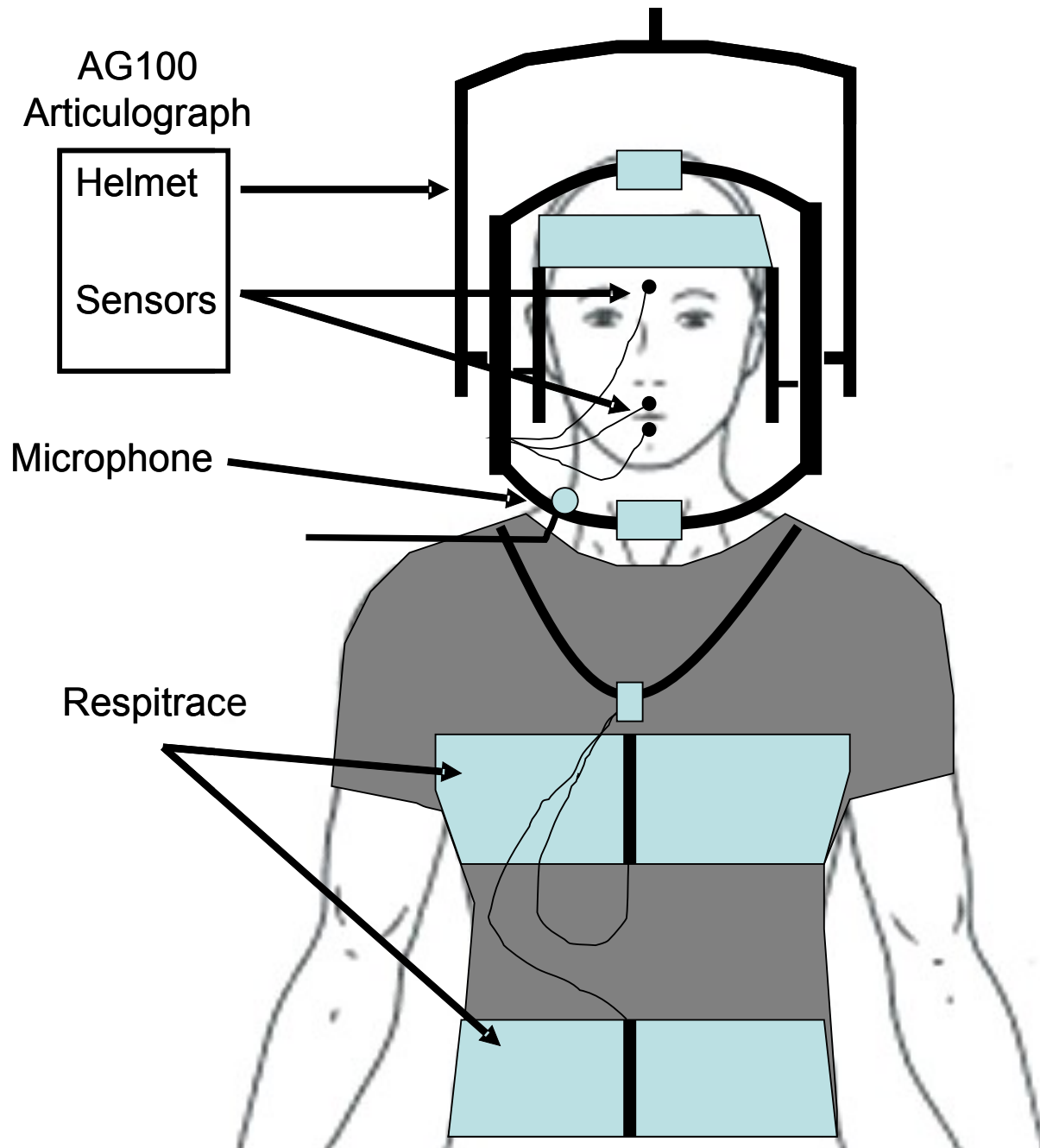
Orofacial movement
- Carstens AG100 Articulograph

Sensor Locations
- upper and lower lips
- mandible
- tongue blade (1 cm from tip)

- Sample frequency: 250 Hz
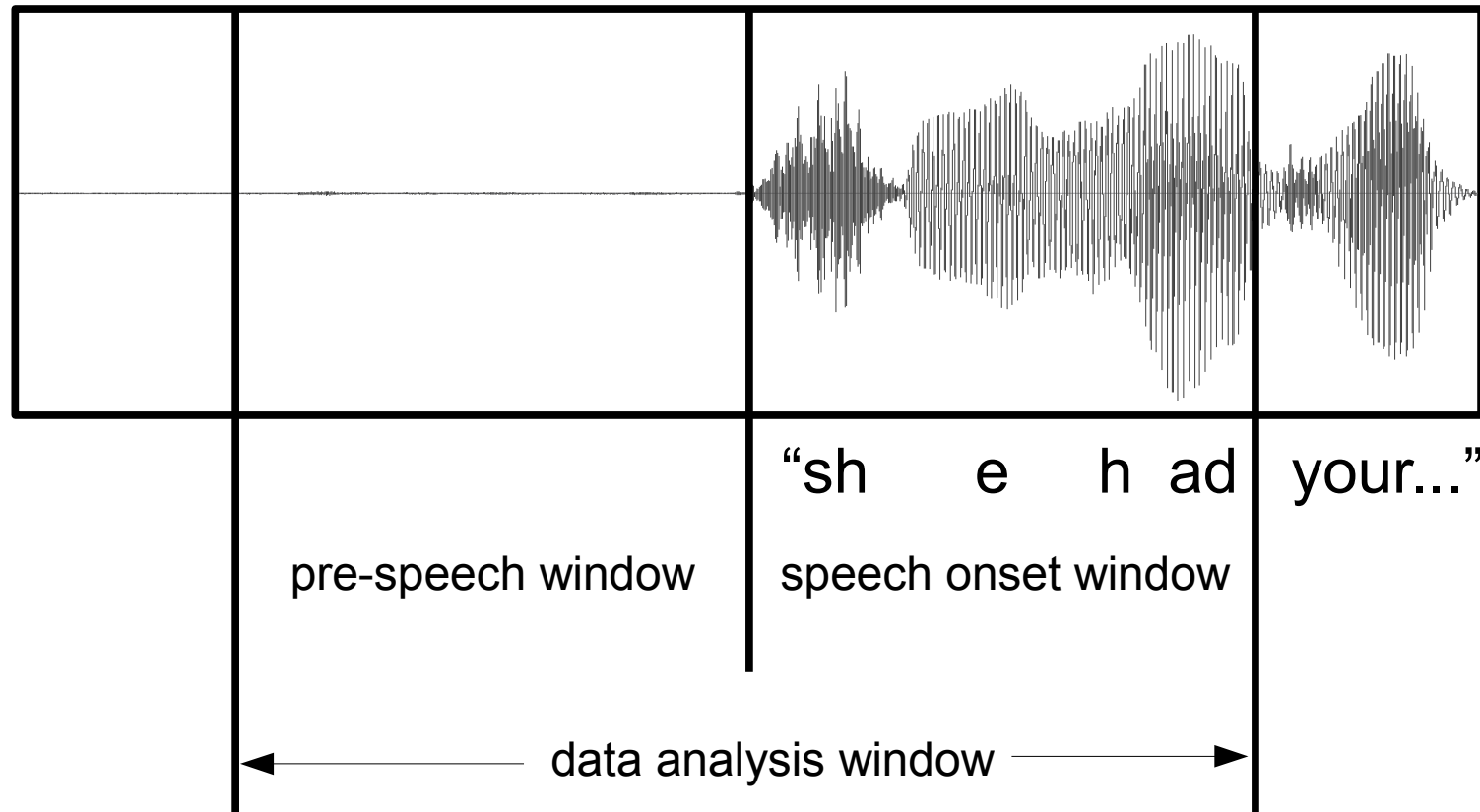- Low pass filtered at 8 Hz

Chest Wall Movement
- Respitrace
- Adjusted for isovolume and referenced to vital capacity

- Sample frequency: 2 Khz
- Low pass filtered at 5 Hz

Speech Acoustics
- Shure M93 microphone
- Sample Frequency 16 KHz

Data Analysis

"sh   e   h ad| your..."

pre-speech window   speech onset window

◄———————— data analysis window ————————►

- For each replicate, a data analysis window was determined using the following method:

- Speech onset window: acoustically defined period between utterance onset and oral stop offset associated with "had."

- Pre-speech window: onset: defined as the equivalent duration of the speech onset window prior to acoustic onset. This period was included because prior analysis revealed this period captured key articulatory and respiratory events.

- Data analysis window: pre-speech window + speech onset window

Data Analysis

Kinematic data included in analysis

- Rib cage history (RC)

- Abdomen history (AB)

- Lip aperture (LA): Euclidean distance between upper and lower lip fleshpoints.

- Mandibular incisor (MI): horizontal and vertical positions

- Tongue blade (TB): horizontal and vertical positions

Data Processing (See Figure)

- Analysis limited to continuous kinematic motion histories within the data analysis window

- Each of 5 replicates underwent (1) linear time normalization (using cubic spline interpolation) so all have equivalent time scale (1000 data points) and (2) z-transform to reduce amplitude variation

Data Analysis

Independent Variables

- **Group**: persons who stutter (PWS) vs. normally fluent speakers (NFS)

- **Time Interval**: The data analysis window was divided into three equal sub-intervals, thus allowing analysis of speech motor variability (1) before utterance onset, (2) around utterance onset, and (3) briefly following utterance onset.

Dependent Variable

- The **mean standard deviation (SD)** of kinematic histories within each time interval served as the dependent variable

- Since TB and MI have two movement dimensions, the standard distance ($[SD_x^2 + SD_y^2]^{1/2}$) was derived. This resulted in a single variability estimate for each fleshpoint marker.

Statistical Analysis

- Repeated measures ANOVA where participant group was a between subjects factor and time interval was the within subjects factor.
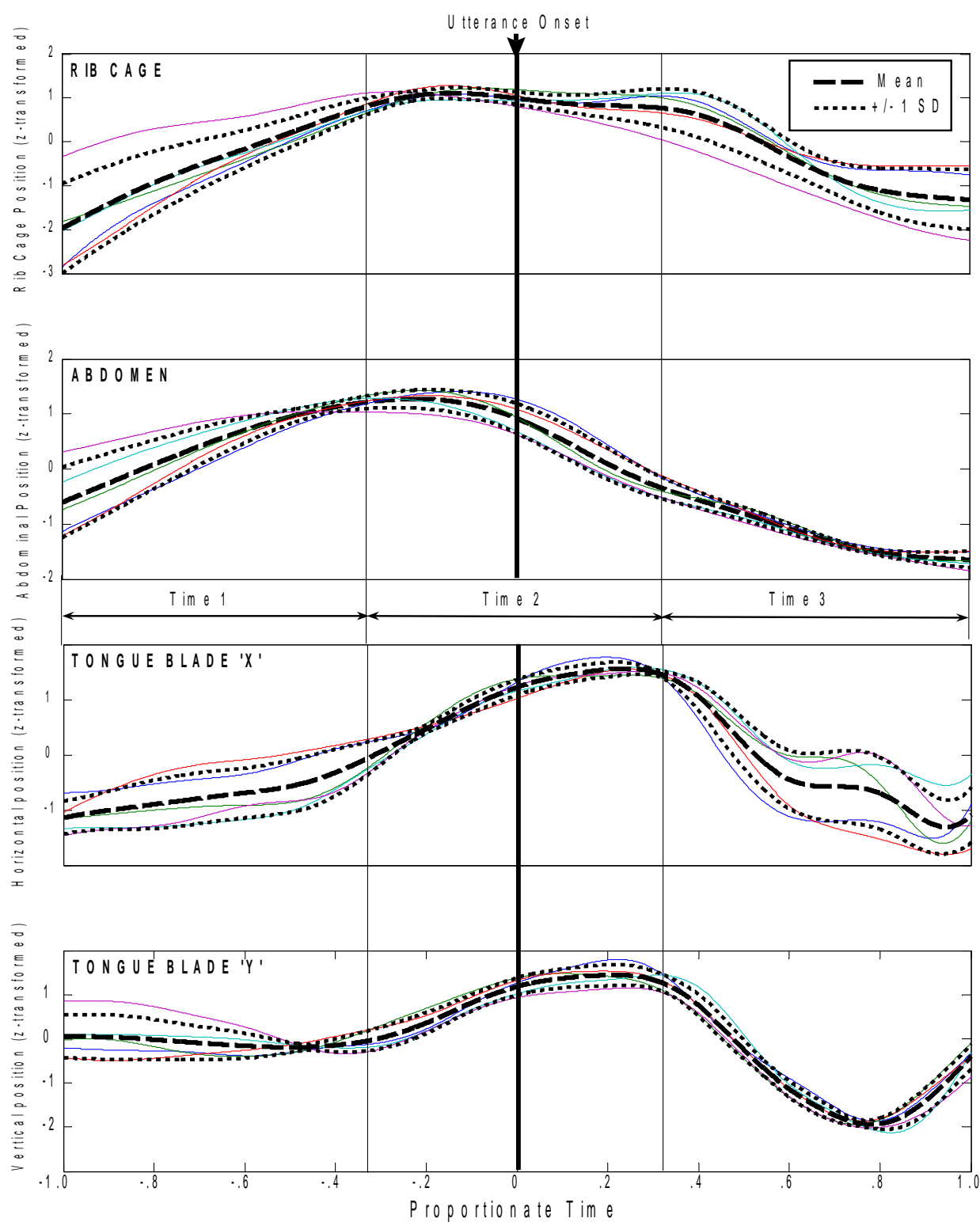
- These plots show the results of the data processing technique for respiratory and tongue blade data for a single speaker.

- Colored lines: Individual replicates

- Heavy black dashed line: mean motion history

- Black broken lines: +/- 1 standard deviation

- The analysis window is subdivided into three time interval (Time 1, Time 2, Time 3).

- The mean of the standard deviation history over each time interval served as the dependent measure.
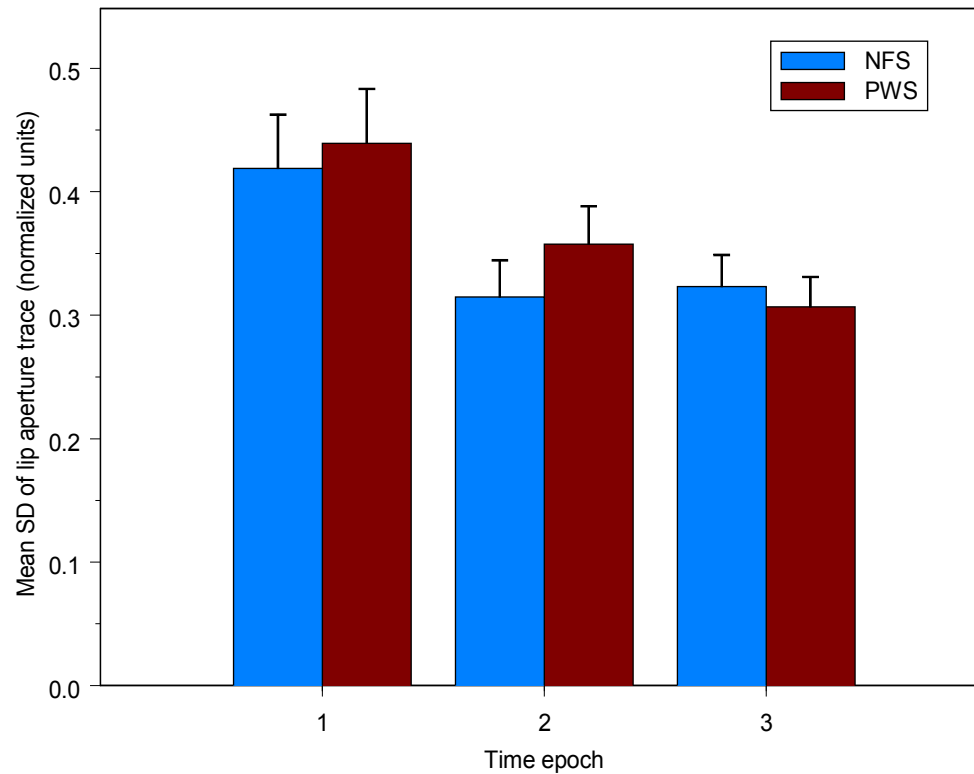
Rib Cage (RC) Results
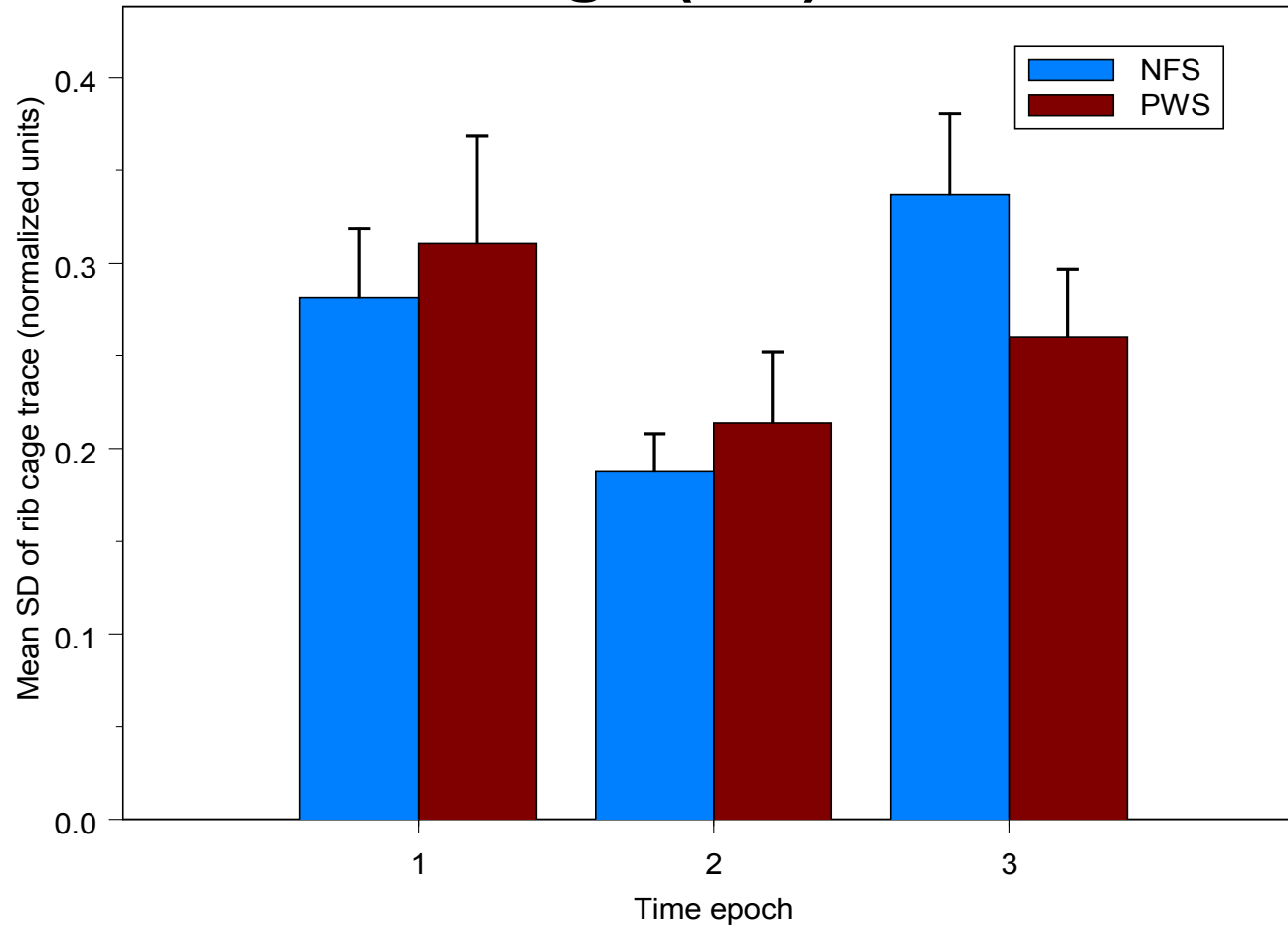
- No significant group main effect, $F(1, 50) = 0.17$, *NS.*

- Significant time main effect, $F(2, 100) = 16.64$, *p*=.0005.

- Significant group-time interaction, $F(2, 100) = 4.92$, *p*=.009.

- Time 1 > Time 2; Time 3> Time 2; Time 1=Time 3

- NS trend for PWS to have smaller mean SD at Time 3
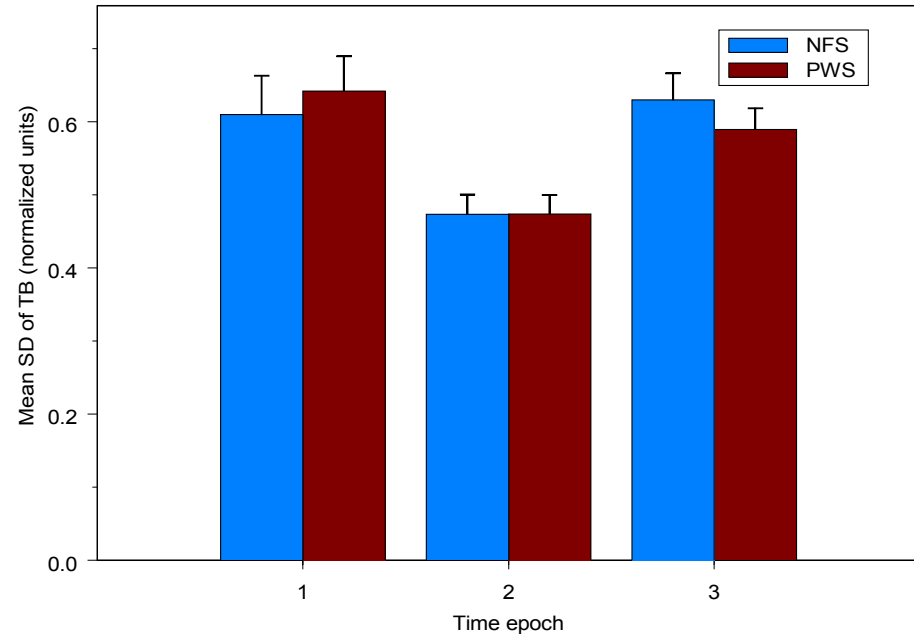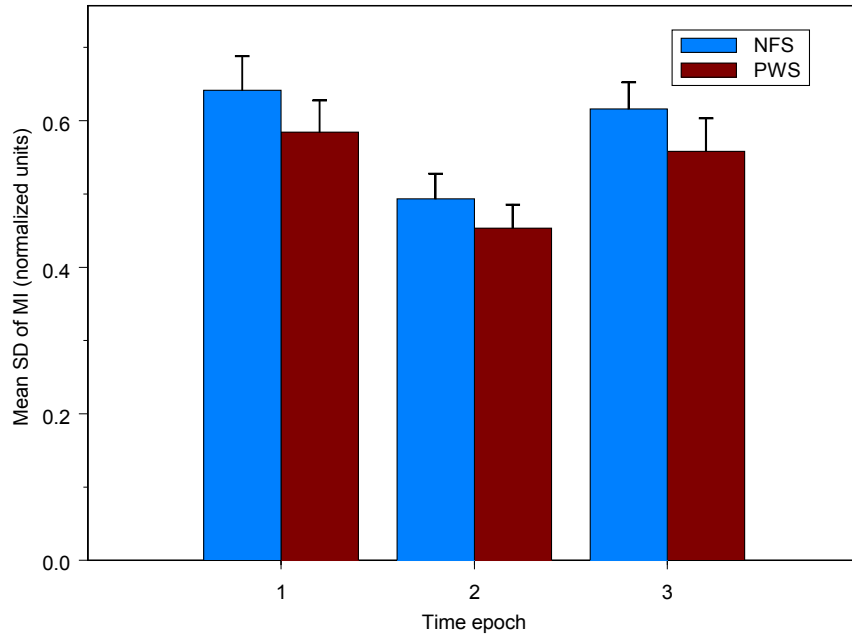
Abdominal Wall (AB) Results
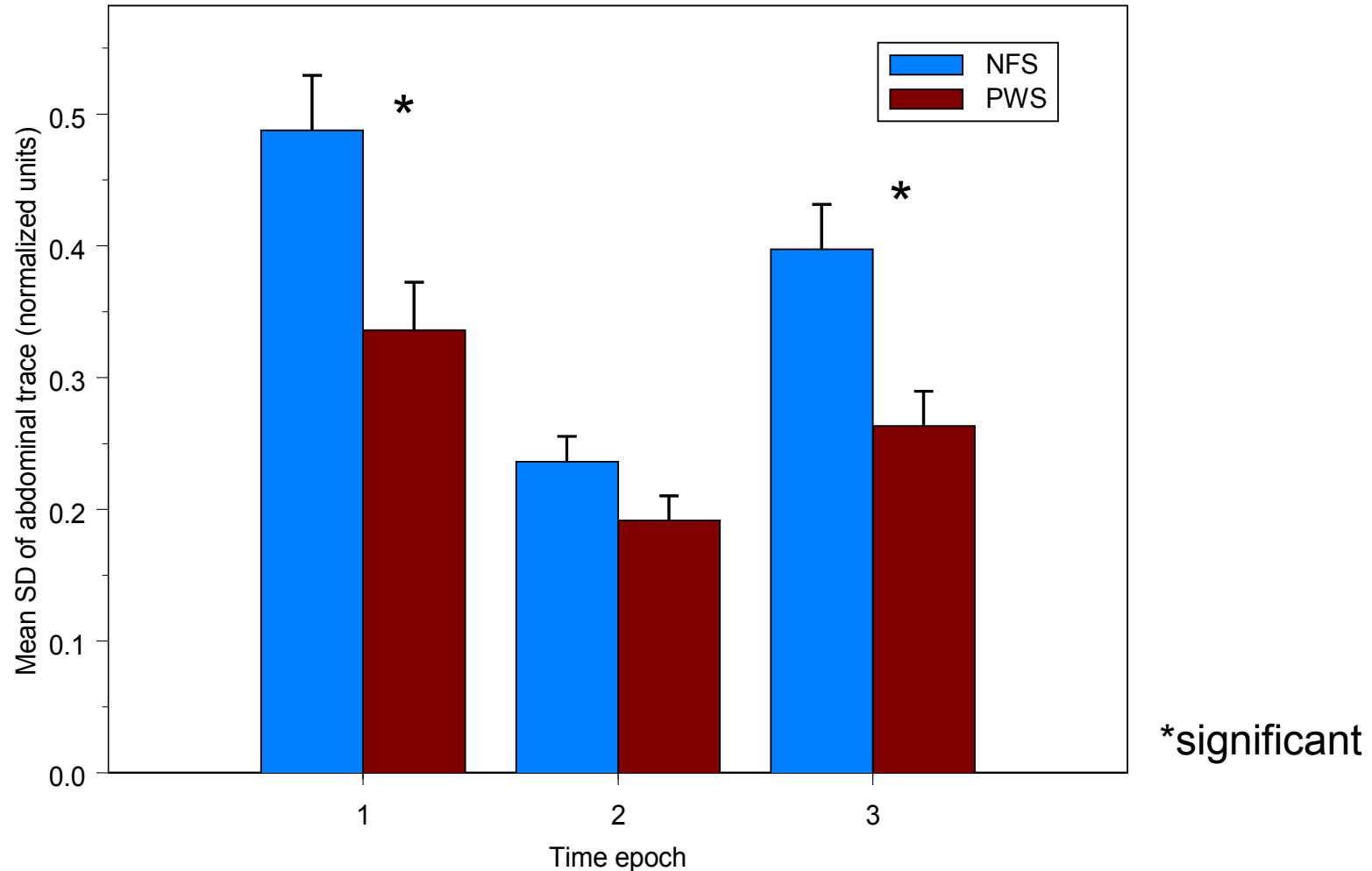
- Significant group main effect, $F(1, 50) = 16.64$, $p=.005$.

- Significant time main effect, $F(2, 100) = 59.78$, $p<.0005$.

- Significant group-time interaction, $F(2, 100) = 5.00$, $p=.008$.

- **PWS have smaller mean SD as compared to NFS**

- Time 1 > Time 2; Time 3> Time 2; Time 1>Time 3

Lip Aperture (LA) Results

- No significant group main effect, $F(1, 50) = 0.14$, *NS*.

- Significant time main effect, $F(2, 100) = 17.17$, *p<.0005*.

- No significant group-time interaction, $F(2, 100) = 1.03$, *NS*.

- Time 1 > Time 2; Time 3 = Time 2; Time 1>Time 3

Mandible (MI) & Tongue Blade (TB) Results

- No significant group main effect for MI [$F(1, 50) = 1.03$, *NS*] or TB [$F(1, 50) = 0.01$, *NS*].

- Significant time main effect for MI [$F(2, 100) = 23.16$, $p<.0005$] and TB [$F(2, 100) = 21.49$, $p<.0005$].

- No significant group-time interaction for MI [$F(2, 100) = 0.11$, *NS*] or TB [$F(2, 100) = 1.01$, *NS*].

- Time 1 > Time 2; Time 3> Time 2; Time 1=Time 3

SUMMARY AND CONCLUSIONS

Both PWS and NFS showed similar patterns in kinematic variability across adjacent time intervals

- In spite of many group-by-time interval interactions, both the PWS and NFS groups showed very similar <u>patterns</u> of kinematic variability across the three analysis periods. Variability was relatively high just prior to utterance onset (Time 1) and then was markedly reduced in the interval around utterance onset (Time 2) and with the exception of LA, variability then increased again early within the utterance (Time 3). This observation was observed across different speech motor subsystems suggesting that, regardless of group or subsystem, there may be less 'tolerance' for variability at utterance onset.

PWS exhibited either (1) reduced or (2) similar levels of kinematic variability at utterance onset as compared to NFS.

- The key group difference between PWS and NFS was an unexpected one. PWS showed <u>reduced</u> variability in the abdominal wall movement as compared to NFS, suggesting that, in some circumstances, PWS might actually show greater motor stability.

- There were no systematic group differences in magnitude of kinematic variability across all the oral articulatory sampled suggesting that utterance level data might not generalize to intervals of shorter duration.

References

Howell, P., Anderson, A.J., Bartrip, J. & Bailey, E. (2009). Comparison of acoustic and kinematic approaches to measuring utterance-level speech variability. *Journal of Speech, Language and Hearing Research, 52*, 1088–1096.

Kleinow, J., & Smith, A. (2000). Influences of length and syntactic complexity on the speech motor stability of the fluent speech of adults who stutter. *Journal of Speech, Language, and Hearing Research, 43*, 548-559.

Namasivayam, A.K, van Lieshout, P., McIlroy, W., & de Nil, L. (2009). Sensory feedback dependence hypothesis in persons who stutter. *Human Movement Science, 28,* 688–707.

Smith, A. & Kleinow, J. (2000). Kinematic correlates of speaking rate changes in stuttering and normally fluent adults. *Journal of Speech, Language, and Hearing Research, 43*, 521-536.

Smith, A. (1999). Stuttering: A unified approach to a multifactorial, dynamic disorder. In N. Ratner & C. Healey (Eds.), Research and treatment of fluency disorders: Bridging the gap (pp. 27-44). Mahwah, NJ: Erlbaum.

Acknowledgments