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Stuttering severity and responses to social-communicative challenge in preschool-age children who stutter

Danra Kazenski1, Barry Guitar1, Rebecca McCauley1,2, William Falls3, Lindsay Stallings Dutko1,4

1Department of Communication Sciences and Disorders, University of Vermont, Pomeroy Hall, 489 Main Street, Burlington, VT 05405, USA, 2Present Address: Department of Speech and Hearing Science, The Ohio State University, 1340 Pressey Hall, 1070 Carmack Road, Columbus, OH 43210-1002, USA, 3Department of Psychology, University of Vermont, John Dewey Hall, 2 Colchester Avenue, Burlington, VT 05405-0134, USA, 4Present Address: Department of Speech Pathology & Audiology, Duke University Hospital, DUMC 3887, Durham, NC 27710, USA

Purpose: This study assessed indices of autonomic arousal and vocal tension during challenge in preschool-age children who do stutter (CWS) and do not stutter (CWNS).

Method: Participants were preschool-age CWS (n = 10) and gender- and age-matched CWNS (n = 10) who performed in two speaking conditions: (1) ‘low’ challenge – naming age-appropriate pictures in a familiar room with the same examiner who administered his/her speech-language prescreening test (2) ‘high’ challenge – recalling the pictures named in condition (1) in a different room with an unfamiliar examiner while wearing acoustic startle electrodes on his/her face. Immediately following the ‘high’ challenge speaking task, the participants’ acoustic startle eyeblink response (ASEB) was measured. Dependent variables were ASEB in the ‘high’ challenge condition and the acoustic measure of mean fundamental frequency (F0) in both challenge conditions.

Results: Findings indicated no significant between-group (CWS vs. CWNS) differences in F0 or ASEB responses. However, CWS-severe (n = 5), when compared with CWS-mild/moderate (n = 5), exhibited a statistically significant increase in F0 in the ‘high’ challenge relative to the ‘low’ challenge condition.

Conclusions: Results were taken to suggest that preschool-age CWS-severe exhibit vocal tension while speaking in conditions of social (e.g. speaking to unfamiliar examiner) and communicative (e.g. recalling from memory names of pictures previously shown) challenge, and such vocal behavior is possibly associated with this subgroup’s difficulty establishing normally fluent speech.

Keywords: Preschool, Stuttering, Acoustic startle, Fundamental frequency, Challenge

Autonomic arousal has long been speculated to be associated with stuttering (e.g. Bruttin and Shoemaker, 1967; Conture and Walden, 2012; Guitar, 2013; Smith, 1999), with such speculation receiving some empirical support. For example, Weber and Smith (1990) reported that extreme autonomic arousal in a stressor condition was positively correlated with stuttering severity and frequency in adults who stutter (AWS), suggesting that such arousal may affect speech motor control. Furthermore, autonomic arousal has been shown to be associated with more variable speech motor control for both adults and children who do not stutter (Kleinow and Smith, 2006). A recent preliminary study utilizing skin conductance response as a primary measure (Arenas and Zebrowski, 2013), indicated that AWS had a significantly greater autonomic conditioned response to an aversive stimulus relative to adults who do not stutter (AWNS).

Unfortunately, less is known about these variables in preschool-age children who stutter (CWS) compared to children who do not stutter (CWNS) closer to the onset of stuttering. Lack of information regarding preschool-age CWS is salient because young CWS typically have minimal experience with stuttering and hence less opportunity to develop learned reactions to stuttering. One exception to this dearth of information relates to empirical studies employing
behavioral measures of expressed emotion, the latter believed to be an indirect index of autonomic activity.

Specifically, findings based on behavioral indices of preschool-age CWS and CWNS’s expressed emotional arousal (e.g. Arnold et al., 2011; Johnson et al., 2010; Ntou rou et al., in press; Walden et al., 2012) appear to support the notion that increases in emotional arousal are associated with childhood stuttering. For example, preschool-age CWS’s stuttering has been reported to increase when increased emotional reactivity is associated with decreased emotional regulation (Walden et al., 2012). As intriguing as these behavioral findings may be regarding preschool-age CWS, the implications might be more comprehensive if they were corroborated by converging lines of evidence, particularly in the form of (non-speech) physiological as well as speech indices of autonomic arousal. Given empirical evidence suggesting that autonomic arousal affects speech motor control in AWS (Kelly et al., 1995; Kleinow and Smith, 2006; Peters and Hulstijn, 1984; Weber and Smith, 1990), measuring physiological responses in preschool-age CWS and CWNS closer to the onset of stuttering should provide useful information about the association of speech motor control and autonomic arousal during the early stages of developmental stuttering.

It seems possible that the association between changes in autonomic or emotional variables and speech motor control activity is apt to be subtle as well as brief in nature, particularly in young children near the onset of stuttering. Thus, as a preliminary attempt to non-invasively measure such possibly subtle autonomic reactions in a preschool-age population, both speech (mean fundamental frequency) and non-speech (acoustic startle eyeblink response (ASEB)) indices of autonomic arousal were employed. Following is a brief discussion of the general background of each measure as well as each measure’s specific application to stuttering.

**Vocal measure fundamental frequency**

**Vocal fundamental frequency (F0),** or pitch, is the vibratory rate of the vocal folds measured in Hertz (Hz). Scherer (2003) demonstrated that increased vocal F0 is robustly correlated with emotional arousal. F0 is affected by changes in the mass and tension of the vocal folds and has been suggested to reflect the emotional state and mood of the speaker (Gobl and Chasaide, 2003; Murray and Arnott, 1993; Scherer, 1982), such as those occurring during under stressful or emotionally arousing speaking conditions (Ruiz et al., 1990; Scherer, 1986; Wittels et al., 2002). In male AWNS, mean F0 has been found to increase significantly in high ‘stress’ situations compared with low ‘stress’ situations (Brenner et al., 1983). However, there are conflicting results regarding between-group differences in the overall variation in mean F0. For instance, Hall and Yairi (1992) demonstrated a low positive correlation between stuttering severity and mean F0 in preschool-age boys who stutter. In contrast, other researchers have reported that the mean F0 of AWS does not significantly differ from AWNS (Healey, 1982; Sacco and Metz, 1989). In this study, F0 will be referred to as an indirect index of vocal tension.

**Acoustic startle eyeblink response**

ASEB is a robust non-speech measure of physiological reactivity (Grillon, 2002; Grillon and Baas, 2003; Mauss and Robinson, 2009). Startle is a defensive, reflexive response consisting of a rapid contraction of the orbicularis oculi muscle, which is innervated by the facial nerve. The ASEB response is a measure of the magnitude and latency of a reflexive eyeblink response to randomly administered brief pulses of high-intensity white noise. Latency (in ms) is the time from the onset of the startle stimulus to the first sign of eyeblink response, with shorter latencies reflecting higher levels of neurophysiological reactivity. The amplitude of startle response has been shown to increase when the person is in an aroused emotional state such as fear (Lang et al., 1990) or anticipatory anxiety (Grillon et al., 1991; Sabatinelli et al., 2001).

To date, the only published studies of ASEB that these authors are aware of has involved AWS and AWNS. For example, Bradley and Lang (2000) found that AWNS exhibited an increase in magnitude of ASEB response when exposed to unpleasant compared to pleasant or neutral affective sounds. Further, Guitar (2003) reported a statistically significant difference (81% higher) mean amplitude of startle response for 14 AWS compared to matched AWNS. In contrast, Alm and Risberg (2007) found that startle amplitude was not significantly associated with anxiety or reactive temperament even though the ‘trait anxiety’ scores for the AWS group were significantly higher than for the controls in their study. Ellis et al. (2008) also measured the latency and peak amplitude of the ASEB in AWS and AWNS and reported non-significant between-group (AWS vs. AWNS) and within-group (AWS-mild vs. AWS-moderate/severe) differences. Ellis et al. (2008) noted considerable individual differences in ASEB, with high standard deviation (SD) variability across participants, particularly in the AWS-moderate/severe (65.2% higher) group when compared to the AWNS group, leading these researchers to conclude that stuttering severity was not associated with acoustic startle response. However, Ellis et al. (2008) did not rule out the possibility that individual differences in temperament or neurophysiological reactivity could temper stuttering severity.
Given the reported findings for these physiological measures, one might expect that having preschool-age CWS experience social (e.g. speaking to an unfamiliar examiner) and/or communicative (e.g. saying aloud names of pictures recalled from memory) challenge may be associated with subtle changes in speech/voice (e.g. changes in $F_o$) and/or non-speech (e.g. ASEB magnitude) indices of autonomic arousal. Specifically, this study attempted to examine the following issues by testing hypotheses particular to each issue.

**Issues examined/hypotheses tested**

With regard to the above, this study investigated four salient issues. The first issue related to whether there are between-group (preschool-age CWS vs. CWNS) differences in acoustic measures of laryngeal reactivity/tension ($F_o$) in a social-communicative speech challenge task. Hypothesis #1 was that CWS, when compared to CWNS, would increase their $F_o$ from ‘low’ to ‘high’ speech challenge conditions. The second issue related to whether there are within-group differences (CWS-severe vs. CWS-mild/moderate) on this same vocal measure. Hypothesis #2 was that CWS-severe, when compared to CWS-mild/moderate, would exhibit an increase in $F_o$ from ‘low’ to ‘high’ speech challenge conditions. The third issue related to whether there are between-group differences in physiological reactivity to a non-speech challenge, measured by peak and latency of ASEB. Hypothesis #3 was that CWS, when compared to CWNS, would exhibit greater mean peak magnitude and shorter (faster) latency ASEB. The fourth issue related to whether there are within-group differences in ASEB response. Hypothesis #4 was that CWS-severe, when compared to the CWS-mild/moderate, would exhibit higher mean magnitude and faster latency of response in the ASEB non-speech challenge condition.

**Methods**

**Participants**

Participants were 10 preschool-age (2:11–5:1; mean 3:9) CWS (7 boys), and 10 gender- and age-matched (±3 months; mean 3:8) preschool-age CWNS (7 boys). CWS were offered participation in this study after their caregiver requested a fluency diagnostic at the University of Vermont Eleanor M. Luse Center clinic (Burlington, Vermont, USA). Six of the CWS were assessed by the fifth author in 2005, and the remaining four CWS and 10 matched CWNS were assessed by the first author using the identical testing protocol from 2005–2006. Both examiners were trained and supervised by the second author.

Children were classified as a CWS for purposes of this study if they (1) were boys or girls between 2:11 and 5:11 years, (2) exhibited normal hearing based on a pure-tone and white noise screening across frequencies at 15 dB, (3) had received the diagnosis of stuttering by a speech-language pathologist with specialty certification in stuttering and presented with ≥2% SS on the frequency section of the Stuttering Severity Instrument-3rd Edition (SSI-3; Riley, 1994), (4) had articulation, and receptive and expressive language development within normal limits as measured by ≥16th percentile on the Fluharty Preschool Speech and Language Screening Test – 2nd Edition (Fluharty-2, Fluharty, 2001) and Peabody Picture Vocabulary Test-III (PPVT-3, Dunn and Dunn, 1997).

Of the 10 preschool-age CWS, five exhibited ‘mild-moderate’ and five ‘severe–very severe’ (n = 5) stuttering based on their overall score on the SSI-3 (see Table 1). Hereafter, the ‘severe–very severe’ group is referred to as ‘CWS-severe’. After establishment of the CWS group, 10 age- (±3 months) and gender-matched CWNS were recruited via flyers in local schools and businesses and via personal communication in the Burlington, Vermont area. Preschool-age CWNS inclusion criteria was the same except they had to exhibit <1% SS, be classified as nonstutterers by a speech-language pathologist with a specialty certification in stuttering and not present with any previous stuttering behavior as reported by the parents.

**Exclusion criteria**

Exclusion criteria for both CWS and CWNS included (1) known cognitive or neurological disorders as reported in parent interview, (2) previous speech or language treatment, and (3) failed hearing screening. Twelve CWS were originally enrolled in the study. Two CWS were excluded (one girl and one boy) because they did not complete the testing protocol due to fatigue, or pass the hearing screening, respectively.

**Procedures**

Parents who expressed interest in response to a newspaper ad or a flyer, which was distributed to Speech-Language Pathologists working at Early Essential Education programs in the greater Burlington, Vermont (USA) area, were sent a packet after an initial phone contact. The packet included a copy of a Lay Summary and Consent form, and an information sheet asking about (a) familial history of speech/language disorders, (b) handedness, and (c) a brief description of the child’s stuttering onset. An appointment for participation in this empirical study was made once all signed materials were received by the researchers. The single research session for both talker groups (e.g. CWS and CWNS) took place at the Eleanor M. Luse Center clinic at the University.
of Vermont campus in Burlington, Vermont, and lasted approximately 1.5 hours. This study’s protocol was approved by the Institutional Review Board at the University of Vermont. For each of the participants, parents signed an informed consent and their children assented. The participants were unpaid volunteers. Each family received a summary report of the child’s speech, language, and hearing results.

Pre-testing conversational sample
Upon arrival, introductions were made and the child and parent were escorted to a treatment room, which was set up for a game. Parent report of dominant handedness was confirmed by having the child throw a beanbag three times at a target and draw a picture (to account for possible differences in hemispheric laterality when measuring ASEB). The researcher and parent then communicatively interacted with the child for approximately 10–15 minutes of conversation while playing a game until at least 300 syllables of the child’s spontaneous speech were elicited. This interaction was video-recorded and was used as one of two speech samples collected for later analysis using the Stuttering Severity Instrument – 3rd Edition (SSI-3; Riley, 1994). When a sufficient syllable count based on a conversational sample was reached for the SSI-3 sample, the testing continued with the ‘low’ challenge situation and then the ‘high’ challenge situation. This order was maintained across participants instead of counter-balancing conditions in order to maximize compliance by starting with the less challenging condition first.

‘Low’ challenge condition: naming pictures
In the ‘low’ challenge situation, the clinician explained that the child would get to be a ‘movie star’ for about 5 minutes and say words into a microphone. The child remained in the familiar clinic room with their parents sitting next to them. A microphone attached to a high-quality digital recorder was then held approximately 6 inches in front of, and slightly below, the child’s mouth. The child was asked to name four familiar and age-appropriate pictures selected from the Fluharty-2 screening booklet: dog, sock, fork, and shoes. The words were selected based on the methodology of Coster (1986) because they have long-duration medial vowels and a C-V-C or C-V-C-C structure. The words were recorded for later analysis of $F_o$.

‘High’ challenge condition: social-communicative speech challenge and ASEB non-speech challenge
The child was then told that he/she would go to ‘astro-naut training’ for approximately 10 minutes. The child was taken by elevator upstairs to an unfamiliar room where the acoustic startle eyeblink (ASEB) response was also performed. The child was seated in a chair next to his/her parent or on the parent’s lap if the

<table>
<thead>
<tr>
<th>#</th>
<th>Sex</th>
<th>Age</th>
<th>SSI-3</th>
<th>Handedness</th>
<th>Family history of stuttering</th>
</tr>
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<tbody>
<tr>
<td>CWS ($n = 10$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>M</td>
<td>3:9</td>
<td>31 (severe)</td>
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</tr>
<tr>
<td>2</td>
<td>M</td>
<td>3:3</td>
<td>19 (moderate)</td>
<td>Right</td>
<td>Immediate</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>4:3</td>
<td>19 (moderate)</td>
<td>Right</td>
<td>Immediate</td>
</tr>
<tr>
<td>4</td>
<td>F</td>
<td>4:10</td>
<td>22 (moderate)</td>
<td>Right</td>
<td>None</td>
</tr>
<tr>
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<td>M</td>
<td>5:1</td>
<td>27 (severe)</td>
<td>Right</td>
<td>Immediate</td>
</tr>
<tr>
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<td>M</td>
<td>3:7</td>
<td>23 (moderate)</td>
<td>Left</td>
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</tr>
<tr>
<td>7</td>
<td>M</td>
<td>3:1</td>
<td>32 (very severe)</td>
<td>Right</td>
<td>Unknown (adopted)</td>
</tr>
<tr>
<td>8</td>
<td>F</td>
<td>4:4</td>
<td>29 (severe)</td>
<td>Right</td>
<td>Immediate</td>
</tr>
<tr>
<td>9</td>
<td>M</td>
<td>3:5</td>
<td>15 (mild)</td>
<td>Right</td>
<td>None</td>
</tr>
<tr>
<td>10</td>
<td>F</td>
<td>3:0</td>
<td>32 (very severe)</td>
<td>Right</td>
<td>None</td>
</tr>
<tr>
<td>CWNS ($n = 10$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td></td>
<td>Right</td>
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</tr>
<tr>
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<td></td>
<td>Left</td>
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</tr>
<tr>
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<td>M</td>
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<td></td>
<td>Right</td>
<td>None</td>
</tr>
<tr>
<td>4</td>
<td>F</td>
<td>4:8</td>
<td></td>
<td>Right</td>
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</tr>
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<td>4:11</td>
<td></td>
<td>Right</td>
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<tr>
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<td>M</td>
<td>3:8</td>
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<td>Right</td>
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<tr>
<td>9</td>
<td>M</td>
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<td></td>
<td>Right</td>
<td>Unknown</td>
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<tr>
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<td>F</td>
<td>3:1</td>
<td></td>
<td>Right</td>
<td>None</td>
</tr>
</tbody>
</table>

Note: Age (years:months); SSI-3 (Stuttering Severity Instrument-3; Riley, 1994); Immediate: an individual in the participant’s immediate family (e.g. father, sibling) stutters or stuttered based on parent report.
child preferred. The child was told about the electrodes, called ‘stickers,’ and was given the opportunity to place an electrode on his/her parent. Three electrodes were then placed on the child (two below the left eye placed 2-cm apart on the orbicularis oculi muscle, and the third on the forehead to act as a ground) using the protocol reported in Guitar (2003). Once the AEB electrodes were in place, the child was asked to remember the words from the pictures he/she saw in the ‘low’ challenge condition (dog, sock, fork, and shoes). If the child was unable to remember the words, prompts were given (“Do you remember the things we wear on our feet?”). Only if the prompts were unsuccessful, the picture(s) were reshown. Once again, the four words were audio recorded in high-quality digital format with a microphone placed approximately 6 inches below and slightly in front of the mouth for later F0 analyses of the isolated medial vowel segments. None of the CWS stuttered during the single-word productions and the children’s volume was controlled by telling them to speak using their ‘normal’ voice. The unfamiliar and novel environment, the placement of the sensors, and the task of remembering words were intended to create a higher challenge condition than when the words were first elicited (Coster, 1986). CWS have also been shown to demonstrate higher emotional reactivity when exposed to environmental change compared to CWNS (e.g. Schwenk, 2007). Picture naming of familiar objects (e.g. dog) was used to minimize the chances that the CWS would stutter in either the ‘low’ or ‘high’ challenge conditions.

Immediately after saying the four words, the child was then told that they would need to listen carefully if they wanted to speak using their

and the child received a toy ‘prize’ after completing this portion of the testing.

**Post-testing conversation sample**

For the last component of the protocol, the child returned to the first testing room where the interactions were again video-recorded. The researcher and parent engaged the child in conversation while playing another age-appropriate game until at least 300 syllables of spontaneous conversation were elicited. This sample was also used for the SSI-3 analysis, as the instrument requires at least two speaking samples.

**Language assessments and hearing screening**

The Fluharty-2 and PPVT-3 tests were then administered. A pure tone (250, 500, 1000, 2000, 4000, 8000 Hz) and white noise hearing screening was performed bilaterally at 15 dB (1000 and 2000 Hz) at the end of the testing. The white noise screening at 15 dB was included because the acoustic startling response was elicited using a white noise stimulus at 95 dB. All participants passed the hearing screening.

**Audio sample analysis**

Following the diagnostic session, the ‘low’ and ‘high’ challenge condition audio samples were then analyzed using the Computer Speech Lab 4400 (CSL4400) and its accompanying F0-adjusted software, the Multi-Dimensional Voice Program (Kay Electronics Corporation, 1999). The entire word-medial vowel of each participant’s spoken word (dog, sock, fork, and shoes) was isolated and analyzed for fundamental frequency (F0). Mean F0 was then calculated across each participant’s production of the four words in ‘low’ and ‘high’ challenge conditions, respectively.

**Pre-analytical data preparation**

**Statistical power**

The relatively small number of cases in this study (N = 10 + 10 = 20), results in an inability to detect small, clinically trivial differences. To assess what the study could detect, a power analyses using PASS 2013 software (Hintze, 2013) was completed for (a) a Pearson correlation, (b) a between-group t-test, and (c) a repeated measures experiment. As Kraemer et al. (2006) suggest, we understand power by estimating the minimum detectable effect size to see how sensitive the study is to differences when they occur. We used Cohen’s (1988) criteria for each (P < 0.05 two-tailed, power = 80%). Cohen’s effect size guidelines, e.g. d = 0.2/0.5/0.8 small/medium/large).

A Pearson correlation with N = 20 (10 + 10) would be able to detect r as low as r = 0.585 with 80% power, a ‘large’ correlation per Cohen’s guidelines. Two groups of 17 (N = 17 + 17) would be required to achieve a ‘large’ effect (80% power) for a two-sample
Therefore, measurement reliability was high. 98.5% and inter-rater agreement was 92.5%.

ables of stuttering from two in-clinic samples, average similar to Ellis conditions. Acoustic startle data were analyzed adequately powered to detect primarily ‘large’ effects, but not ‘medium’ or ‘small’ effects.

Pre-analyses of potential covariates: Age and handedness
Correlation analyses were carried out between age (in months) and the measured outcomes: (1) ASEB initial magnitude and latency as well as mean magnitude and latency across five trials and (2) change in mean \( F_o \) from ‘low’ to ‘high’ challenge conditions. Age was not significantly correlated with any of the outcome measures in CWS-severe compared to CWS-mild/moderate or in CWS compared to CWNS. Further, handedness across all participants was not found to be significantly correlated (\( P > 0.05 \)) with peak magnitude or latency of startle response. Therefore, age and handedness were not included as covariates in our repeated measures analyses.

Measurement reliability
Three of the ten CWS participants were randomly selected to assess both intra- and inter-rater measurement reliability. Intra-rater reliability of SSI-3 stuttering severity scores was carried out by the first author who reanalyzed the two conversation samples video recorded in the clinic. Inter-rater reliability was completed by an experienced certified speech-language pathologist with a specialty in stuttering (co-author) using the same video samples. Reliability was conducted for (1) SSI-3 categorical severity ratings (e.g. mild, moderate, severe, very severe) and (2) SSI-3 numerical score (frequency or percent syllables of stuttering from two in-clinic samples, average duration of the three longest stuttering moments plus the physical concomitants subscale scores).

Inter- and intra-rater agreement was 100%, Cohen’s kappa = 1.0 (\( P = 0.01 \)) for overall categorical severity rating on the SSI-3. Overall SSI-3 numerical score intra-rater agreement (mean absolute difference from original SSI-3 score/mean original SSI-3 score) was 98.5% and inter-rater agreement was 92.5%. Therefore, measurement reliability was high.

Statistical analyses
Two repeated measures analyses of variance (ANOVAs) using General Linear Model procedures with IBM SPSS Statistics software (IBM Corp, 2010) were conducted to compare between-group (Hypothesis #1) and within-group (Hypothesis #2) mean change in \( F_o \) from the ‘low’ to ‘high’ challenge conditions. Acoustic startle data were analyzed similar to Ellis et al.’s (2008) procedures. \( T \)-tests were performed to compare between-group (CWS vs. CWNS – Hypothesis #3) and within-group (CWS-mild/moderate vs. CWS-severe – Hypothesis #4) differences in mean ASEB startle response peak magnitude and latency for (a) the initial startle trial (b) the mean across all five trials.

Results
Descriptive analyses
Stuttering severity
To calculate stuttering severity scores with the SSI-3, the two in-clinic speaking samples (at least 300 syllables each) were transcribed for each participant. For all CWS (\( n = 10 \)), the mean SSI-3 score was 24.90 (SD = 6.14), which corresponds to a severity rating of ‘moderate’ (see Table 1). The mean SSI-3 score for the CWS-severe group was 30.2 (SD = 2.13; range 27–32) and the CWS-mild/moderate group mean was 19.6 (SD = 3.13; range 15–23). All CWNS met the inclusion criteria of ≤1% syllables stuttered.

Speech and language
Participants scored at or above the 16th percentile (1 SD below the mean) on all sub-categories on the Fluharty-2 (Fluharty, 2001) comprehensive assessment. One exception was a CWS who scored at the 9th percentile on the articulation screening of the Fluharty-2. This child met all other inclusion protocol and was included in the experiment.

Hypotheses-driven analyses
Hypotheses 1 and 2: Between and Within-Group Vocal Measures in ‘Low’ and ‘High’ Challenge Conditions
Hypothesis 1: Between-group (CWS vs. CWNS) differences in the vocal measure (\( F_o \)) from ‘low’ to ‘high’ challenge conditions. Results of two between-group repeated measures ANOVAs (employing General Linear Model procedures) indicated no significant between-group (CWS vs. CWNS) differences on the measured acoustic variable \( F_o \).

Hypothesis 2: Within-group differences (CWS-severe vs. CWS-mild/moderate) in \( F_o \) from ‘low’ to ‘high’ challenge conditions. There was a statistically significant within-group interaction between stuttering severity and change in \( F_o \) from ‘low’ to ‘high’ challenge conditions \( (F(1,8) = 8.18, P = 0.02; \) Cohen’s \( d = 1.81 \) ‘large’ effect size; see Fig. 1). Partial \( \eta^2 \) (partial eta-squared; \( \eta^2 = 0.51 \)) indicates that the interaction of stuttering severity and ‘low’ and ‘high’ challenge conditions accounts for 51% of the variability in \( F_o \). Specifically, CWS-severe demonstrated a positive mean change of \( F_o \) (mean = +35.98; SEM = 15.33), while CWS-mild/moderate showed a negative mean change (mean = −36.91; SEM = 15.77; see Table 2).
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Hypothesis 2: Relation between CWS’s stuttering severity and change in $F_o$ from conditions of ‘low’ to ‘high’ challenge. Spearman’s rank correlation coefficient (rho) nonparametric analysis indicated that change in mean $F_o$ was positively correlated with SSI-3 scores (rho = 0.77; P < 0.01; see Table 3), such that as stuttering severity increased, change in mean $F_o$ from ‘low’ to ‘high’ challenge conditions increased.

Hypotheses 3 and 4: Between and Within-Group Acoustic Startle Blink Response

Non-significant between-group (CWS vs. CWNS) and within-group (CWS-severe vs. CWS-mild/moderate) differences in ASEB. Results of t-test comparisons indicated no statistically significant between-group group differences ($P > 0.05$) in initial startle latency (Table 4) or peak amplitude or mean startle across trials (Table 5). Cohen’s $d$ effect size for mean latency across the five trials for CWS-severe compared to CWS-mild/moderate was 0.86, which is a ‘large’ effect, in the opposite expected direction of Hypothesis #4, even though the results were not significant ($P = 0.23$).

Ancillary analyses

Hypothesis #4: Within-Group Differences in Acoustic Startle Blink Response

Relative to Hypothesis 4, ancillary analyses of the within-group (CWS-severe vs. CWS-mild/moderate) ASEB data were conducted per Ellis et al. (2008): (a) median latency and (b) variability in mean startle magnitude across the five startle trials; (c) the difference between the initial and final stimulus trial magnitudes, or habituation rate.

For ancillary analysis (a), median startle latency across the five trials was 41% faster for CWS-mild/moderate (50.0 milliseconds) than CWS-severe (70.5 milliseconds). For ancillary analysis (b), within-group variability (SD) in mean startle magnitude across trials was 168% higher for CWS-severe (485.59) compared to CWS-mild/moderate (337.67). Further, the variability in startle magnitude (SD) for the initial trial only was 75% higher for CWS-severe (592.18) compared to CWS-mild/moderate (337.67). For

There was a non-significant main effect of stuttering severity across time from ‘low’ to ‘high’ challenge conditions ($F(1,8) = 0.014$, $P > 0.05$).

Table 2 Mean change in $F_o$ from ‘low’ to ‘high’ challenge conditions (a) Between-group (preschool-age CWS vs. CWNS peers) and (b) Within-group (CWS-Severe vs. CWS-Mild/Moderate)

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean (SEM)</th>
<th>P</th>
<th>Cohen’s $d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>4.54 (14.74)</td>
<td>0.87</td>
<td>0.03</td>
</tr>
<tr>
<td>All CWS (n = 10)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All CWNS (n = 10)</td>
<td>1.28 (11.89)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(b)</td>
<td>35.98 (15.33)</td>
<td>0.02</td>
<td>8.18</td>
</tr>
<tr>
<td>CWS-mild/severe (n = 5)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CWS-mild/moderate (n = 5)</td>
<td>-26.91 (15.77)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Sigma of startle is given in arbitrary analog to digital units derived from the electromyographic signal.

Table 3 Spearman’s rank correlation coefficient (rho) between CWS participants’ Stuttering Severity Instrument (SSI-3, Riley, 1994) scores and change in $F_o$ from conditions of ‘low’ to ‘high’ challenge

<table>
<thead>
<tr>
<th>Measure</th>
<th>$F_o$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSI-3 Score</td>
<td>rho = 0.77*</td>
</tr>
</tbody>
</table>

*P < 0.01.

Table 4 ASEB Mean Initial Trial Magnitude and Latency (a) between-group (CWS vs. CWNS) and (b) within-group (CWS-severe vs. CWS-mild/moderate)

<table>
<thead>
<tr>
<th>Group</th>
<th>Initial trial magnitude*</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (SEM)</td>
<td>P</td>
<td>Cohen’s $d$</td>
<td></td>
</tr>
<tr>
<td>(a) All CWS (n = 10)</td>
<td>1038 (147.33)</td>
<td>0.28</td>
<td>0.50</td>
</tr>
<tr>
<td>All CWNS (n = 10)</td>
<td>1244 (108.11)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(b) CWS-severe (n = 5)</td>
<td>941 (151.01)</td>
<td>0.54</td>
<td>0.40</td>
</tr>
<tr>
<td>CWS-mild/moderate (n = 5)</td>
<td>1136 (264.83)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Group</th>
<th>Initial trial latency (milliseconds)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (SEM)</td>
<td>P</td>
<td>Cohen’s $d$</td>
<td></td>
</tr>
<tr>
<td>(a) All CWS (n = 10)</td>
<td>72.70 (19.24)</td>
<td>0.89</td>
<td>0.06</td>
</tr>
<tr>
<td>All CWNS (n = 10)</td>
<td>68.90 (17.73)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(b) CWS-severe (n = 5)</td>
<td>86.80 (34.90)</td>
<td>0.50</td>
<td>0.45</td>
</tr>
<tr>
<td>CWS-mild/moderate (n = 5)</td>
<td>58.60 (18.68)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
ancillary analysis (c), difference scores from the initial to final startle trials (habituation rate) were not statistically significantly ($P = 0.76$) different between CWS-mild/moderate and CWS-severe. Specifically, CWS-mild/moderate demonstrated a decrease in magnitude ($-27.8$) but CWS-severe had an increase in magnitude ($+60.0$) from the first to the last trial.

Discussion

The purpose of this study was to investigate possible between-group (preschool-age CWS vs. CWNS) and within-group (CWS-mild/moderate vs. CWS-severe) differences in autonomic arousal in non-speech ASEB and in vocal tension during ‘low’ and ‘high’ social-communicative speech challenge conditions. In general, these measures are germane to a comprehensive understanding of the association between emotional processes and childhood stuttering. Specifically, it was speculated that disrupted speech motor control during autonomic arousal may differentiate subgroups of preschool-age CWS, possibly suggesting that these subgroups may differ in the ability to establish normally fluent speech at a young age. This study resulted in four main hypotheses-driven findings to be discussed below, followed by a brief general discussion, caveats, and conclusions.

**Main Finding #1: Non-significant Between-Group Differences in $F_0$**

The first between-group main finding indicated that CWS and CWNS ($n = 10$ each) do not significantly differ in vocal measures of $F_0$ in challenge conditions, rejecting Hypothesis #1. This appears to be due to the fact that the subgroups of CWS (CWS-severe and CWS-mild/moderate) had opposite responses to these conditions which canceled the other out when all CWS were combined as a group for the assessment of this vocal measure ($F_0$; see Fig. 1). Results were taken to suggest that whole group comparisons may obfuscate such subgroup differences, and perhaps this accounts for non-statistically significant findings in studies in which the data for CWS-severe and CWS-mild/moderate subgroups are combined into one talker group.

**Main Finding #2: Within-group Differences in $F_0$ from ‘Low’ to ‘High’ Challenge Conditions**

The second main finding (within-group) indicated that CWS-severe and CWS-mild/moderate have opposing vocal responses when exposed to a social-communicative challenge speaking condition (e.g. recalling words aloud in an unfamiliar environment with an unfamiliar examiner while wearing acoustic startle response electrodes). Specifically, CWS-severe presented with increased $F_0$ (pitch) from ‘low’ to ‘high’ challenge, suggesting more laryngeal tension, while CWS-mild/moderate’s pitch decreased (Hypothesis #2). Correlations also revealed that as stuttering severity increased, change in mean pitch increased from ‘low’ to ‘high’ challenge conditions.

Main finding #2 suggests that the social-communicative challenge condition was associated with increased laryngeal tension but only among the children with more severe stuttering (CWS-severe). This finding is thought to be salient because such laryngeal tension may reflect a greater vulnerability to challenge-induced disruption specific to the CWS-severe group, reflecting subtle, context-dependent differences in speech motor control relative to children with milder stuttering. Perhaps this vocal behavior under a challenge condition is possibly associated with this subgroup’s difficulty establishing normally fluent speech.

**Main Finding #3: Non-significant Between-Group Differences in Acoustic Startle Response**

The third main finding in between-group (CWS vs. CWNS) ASEB response is consistent with those of Ellis et al. (2008) for CWS and Alm and Risberg (2007) for AWS. This study showed no statistically significant group differences in mean acoustic startle magnitude and latency as predicted by Hypothesis #3. The results suggest that CWS do not differ in underlying physiological reactivity – at least relative to facial nerve reflexive activity – when exposed to a non-speech challenge condition.

### Table 5 Group ASEB: Mean Across 5 Startle Trials (a) between-group (CWS vs. CWNS) and (b) within-group (CWS-severe vs. CWS-mild/moderate)

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean peak magnitude*</th>
<th>Mean latency (milliseconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SEM)</td>
<td>$P$</td>
</tr>
<tr>
<td>(a)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All CWS ($n = 10$)</td>
<td>1059 (121.09)</td>
<td>0.90</td>
</tr>
<tr>
<td>All CWNS ($n = 10$)</td>
<td>1080 (109.24)</td>
<td></td>
</tr>
<tr>
<td>(b)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CWS-severe ($n = 5$)</td>
<td>1074 (80.79)</td>
<td>0.97</td>
</tr>
<tr>
<td>CWS-mild/moderate ($n = 5$)</td>
<td>1085 (217.16)</td>
<td></td>
</tr>
</tbody>
</table>

*Magnitude of startle is given in arbitrary analog to digital units derived from the electromyographic signal.
MainFinding #4: Non-significant Within-group Differences in Acoustic Startle Response
The fourth and final main finding (within-group), was that CWS-severe did not significantly differ from CWS-mild/moderate in acoustic startle response magnitude or latency, rejecting Hypothesis #4. The results suggest that subgroups of young CWS do not differ in underlying physiological reactivity – relative to facial nerve reflexive activity – during a non-speech challenge condition.

General discussion
One finding of general relevance to the purpose of the present study is that changes in vocal tension ($F_v$) from ‘low’ to ‘high’ challenge conditions differ from changes in non-speech physiological ASEB measures between the same conditions. Specifically, $F_v$ increased for the CWS-severe group while their initial and mean peak magnitude ASEB responses were actually lower than CWS-mild/moderate. Below we discuss five possible accounts for this discrepancy.

Individual differences
One possible interpretation of present findings is that there may be appreciable individual differences in the degree to which autonomic arousal was triggered among CWS by this study’s ‘high’ challenge condition. In other words, differences between the vocal and startle indices of autonomic arousal may be associated with high within- and between-group variability of the ASEB magnitude results, particularly in the CWS-severe group.

Inter-individual differences
CWS-mild/moderate actually decreased pitch from ‘low’ to ‘high’ challenge. Coster (1986) suggested that contextual or situational factors may critically affect individual variation in physiological responses. It is therefore possible that the ‘high’ challenge condition in this study was not comparably associated with autonomic reactivity among all the participants. Ideally, an autonomic measure would have been collected in both ‘low’ and ‘high’ challenge conditions. However, this study’s protocol combined the methodology of two previous studies: (1) Guitar (2003) in which one startle response testing condition significantly differentiated AWS and AWNS and (2) Coster (1986) in which vocal measures were collected in ‘low’ and ‘high’ challenge conditions, with the ‘low’ condition being a familiar speaking environment. For these reasons, and to maximize the novelty of the ‘high’ challenge condition, startle response was only collected in the ‘high’ challenge condition in this study.

Changes in stuttering severity possibly associated with differences in emotion regulation
It is also possible that the current results are consistent with recent findings that stuttering frequency increases with decreased emotional regulation (Arnold et al., 2011), even more so when lower regulation is associated with higher emotional arousal (Walden et al., 2012). If CWS-mild/moderate exhibit greater self-regulation during speech production in a challenge condition, this may allow them to maintain lower stuttering severity in general and ‘inoculate’ them from an increase in stuttering severity. This ‘inoculating’ or ‘protective’ factor may also improve treatment outcomes (shorter treatment duration and less risk of relapse). This is an interesting question which may be answered in future empirical investigations.

Between-group differences in prior exposure to testing setting
We posit that the CWNS group responded similarly to both challenge conditions because the CWNS participants did not have prior exposure to the testing setting while the CWS had one previous session as part of their initial fluency diagnostic at the clinic. This difference was controlled for in this experiment by allowing the CWNS to have at least 10 minutes of quiet free play with their parents to help them come to a baseline level of arousal before testing in the ‘low’ challenge situation. This relative lack of exposure to the testing setting may have influenced the vocal measure results.

Within-group differences in stuttering severity
It is also possible that discrepancies in stuttering severity are associated with within-group differences in stuttering severity. Specifically, within-group differences in stuttering severity for CWS may be related to speech motor control deficits independent of underlying physiological reactivity. Greater stuttering severity has been shown to reflect reduced volitional vocal motor control due to instability in the feed-forward and afferent feedback control subsystems of people who stutter (e.g. Ludlow and Loucks, 2003; Max et al., 2004). It is possible that such reduction in volitional vocal motor control begins in childhood but at present this remains an open empirical question. We suggest that this factor has a greater effect on CWS-severe during speech production, which may explain the increase in $F_v$ from the ‘low’ to ‘high’ challenge conditions for CWS-severe. If so, this would be consistent with results of previous studies in AWS and AWNS (e.g. Weber and Smith, 1990) indicating that speech tasks elicited greater autonomic arousal than non-speech tasks, with the former also correlated with increased stuttering behavior.

Caveats
Sample size was a limiting factor in this study. To plan for future studies, a univariate two-group repeated
measures ANOVA using the Greenhouse-Geisser correction was conducted to determine the number of participants required for 80% power to detect an interaction between CWS-severe and CWS-mild/moderate from ‘low’ to ‘high’ challenge at a significance level of 0.05. The sample size required in each group within the CWS (e.g. CWS-severe and CWS-mild/moderate) for Fe analysis is six participants. Despite these results, for this study’s five participants per group, there was a significant (P < 0.05) difference between the two severity levels for Fe.

Sequencing, carryover, or lingering effects of the challenge conditions may also have affected the results as all participants experienced the ‘low’ challenge condition prior to the ‘high’ challenge condition. This order was selected to maintain compliance of the preschool-age participants. However, counterbalancing the challenge conditions may need to be considered in future studies.

Also, loudness level of the speech sample has been shown to affect Fe in adults (Brockman et al., 2008). Loudness was not strictly controlled for or measured in this study, other than directing the children to use their ‘normal’ speaking volume and to maintain a mouth-to-microphone distance of approximately 6 inches below and slightly in front of the mouth for all participants.

Conclusions
Present results suggest that a social-communicative speech challenge condition affects CWS-severe differently than CWS-mild/moderate even though there were no between-group (CWS vs. CWNS) or within-group differences in the underlying physiological responses to a non-speech challenge ASEB task. Specifically, CWS-severe, when compared to CWS-mild/moderate, presented with increased vocal tension during speech production in the ‘high’ speech challenge condition. This finding is thought to be salient because such laryngeal tension may reflect a greater vulnerability to challenge-induced disruption specific to the CWS-severe group, reflecting subtle, context-dependent differences in speech motor control relative to children with milder stuttering.

Present findings were also taken to suggest that future research on reactivity in people who stutter should consider examining within-group data by stuttering severity (severe/very severe and mild/moderate subgroups of CWS) in addition to between-group comparisons. Clearly, present findings indicate that further research is warranted with more participants, including school-age children and long-term follow-up, to verify whether findings obtained with this study’s relatively small sample size can be replicated and to test more specific hypotheses regarding the relation between stuttering severity and laryngeal tension during speech-related challenges over time.

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References


