SYMPATHETIC AND PARASYMPATHETIC ASSOCIATES OF CHILDHOOD STUTTERING

By

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To my amazing wife, Kristin, for her unwavering and infinite support

To my son, Arlo, always bringing happiness and joy into my life.

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CHAPTER I

INTRODUCTION

The association between emotional processes and developmental (childhood) stuttering has been empirically assessed with increasing interest over the past decade (e.g., Anderson, Pellowski, Conture & Kelly, 2003; Arnold, Conture, Key, & Walden, 2011; Eggers, De Nil, & Van den Bergh, 2009, 2010; Embrechts, Ebben, Franke & van de Poel, 2000; Felsenfeld, van Beijsterveldt & Boomsma, 2010; Johnson, Walden, Conture, & Karrass, 2010; Jones, Conture & Walden, 2011; Karrass, Walden, Conture, Graham, Arnold, Hartfield & Schwenk, 2006; Schwenk, Walden & Conture, 2007; Walden, Frankel, Buhr, Johnson, Conture, & Karrass, 2012). Although findings from these studies do not indicate whether emotions are the cause, correlate, or consequence of stuttering, they do provide strong support for an association between emotion and childhood stuttering. As the following brief review of these empirical investigations shows, extant support for this association comes from several lines of evidence.

Emotions and Childhood Stuttering

To date, evidence for an association between emotion and childhood stuttering has been based on caregiver report, behavioral observation, and psychophysiological studies[1]. Using such methodologies, researchers have studied emotional reactivity and

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[1] Although various methodology, in particular psychophysiology, have also been used to study emotion processes of adults who stutter (AWS), children rather than adults are the subject of the present investigation. Thus, wherever possible the present study has

regulation during naturalistic and various experimental conditions. Although such emotional processes can be subdivided in several ways, two of the more common subdivisions involve positive and negative emotion. With regard to stuttering, most empirical and theoretical attention has been paid to negative emotionality, however, for preschool-age children it seems appropriate to study both elements (i.e., positive and negative). For example, Adams' (1992) suggests a possible association between childhood stuttering and positive emotionality. Following is a brief review of each line of evidence regarding the association between emotion and childhood stuttering.

Among various between-group differences, findings from *parental report questionnaires* indicate that preschool-age children who stutter (CWS), compared to those who do not stutter (CWNS), display: a) less temperamental adaptability, distractibility and rhythmicity (Anderson, Pellowski, Conture, & Kelly, 2003), b) increased reactivity and greater difficulty regulating emotions (Karrass et al., 2006), c) poorer attention regulation skills (Felsenfeld, van Beijsterveldt, & Boomsma, 2010; Karrass et al., 2006), a skill implicated in emotion regulation (Rothbart, Ahadi, & Evans, 2000), and d) lower inhibitory control, attention shifting as well as higher anger/frustration (Eggers, De Nil, & Van den Bergh, 2010). These findings provide evidence that CWS (when compared to CWNS) display cross-situationally stable differences in a variety of emotional processes that appear associated with the development of stuttering.

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focused on preschool-age children who stutter, the age cohort during which stuttering typically begins. For a general review of the literature on psychophysiology and stuttering in AWS, see Appendix A.

Using another methodological approach, that is, *direct observation of behavior* or *experimental testing*, researchers have reported that preschool-age CWS, compared to CWNS, exhibit: a) difficulty habituating to irrelevant environmental stimuli (Schwenk, Conture, & Walden, 2007), b) less ability to flexibly shift attention to and from a stimulus, especially in a negative arousing situation (Bush, 2006), c) more negative emotional expressions in a disappointing gift condition (Johnson, Walden, Conture, & Karrass, 2010), d) lower efficiency of the orienting subsystem of the attentional system (Eggers, De Nil & Van den Bergh, 2012), as well as e) more negative emotion and self-speech during an emotionally frustrating task (Ntourou, Conture, Walden, 2011).

In addition, within-group behavioral observation indicated that for CWS: a) emotionally reactive behaviors were significantly more likely to be initiated prior to and during *stuttered* than *fluent* utterances (Jones, Conture, Frankel, & Walden, 2010), b) decreased duration and frequency of behavioral regulatory strategies is significantly related to more stuttering (Arnold, Conture, Key, & Walden, 2011), c) increased emotional arousal/reactivity, when associated with decreased emotion regulation, is significantly related to increased stuttering (Walden et al., 2012), and d) emotion regulation behaviors are significantly related to increases in stuttering (Ntourou, Conture, Walden, 2011). Unlike caregiver reports (which are based on more average or overall impressions), behavioral observations appear to provide insights into CWS' emotional responding to specific challenging situations (e.g., a disappointing gift experience; Johnson et al., 2010) as well as concomitant changes in speech fluency. In general, findings based on behavioral observation seem to suggest that changes in CWS's emotional processes, particularly emotion regulation, are associated with changes in their stuttering. Thus, behavioral observations, when compared to caregiver reports, may better account for CWS's variability of stuttering across situations, with such variations being one of the more salient hallmarks of childhood stuttering.

Another line of evidence regarding childhood stuttering involves *psychophysiological measures*. To this writer's knowledge, there are presently a very limited number of psychophysiological studies of emotions in preschool-age CWS. Jones, Buhr, Frankel, Conture, & Walden (2011) reported that preschool-age CWS, when compared to their CWNS peers, exhibited: a) lower RSA across listening-viewing and speaking conditions, b) no difference in RSA during positive and negative conditions, and c) lower RSA during a speaking task following a positive emotion condition. A particularly salient finding was that CWS exhibited a *decrease* of RSA from baseline to speaking, whereas CWNS exhibited an *increase* of RSA from baseline to speaking. These subtle to no-so-subtle regulatory problems may make it difficult for CWS to easily, efficiently and quickly engage in social-communicative situations. Alternatively, Arnold et al. (2011) reported no significant between-group differences in electroencephalograms (EEGs) of cortical correlates of emotional reactivity and regulation during emotionally-valenced listening-viewing conditions. Although inconclusive, findings (e.g., Jones et al., 2011) from psychophysiological studies appear to suggest that CWS may exhibit different emotional processes across situations and in response to challenge.

The above three lines of evidence (i.e., caregiver reports, behavioral observation and psychophysiology) appear to support, to greater or lesser degrees, the notion that emotion is associated with stuttering. However, with the notable exception of some studies based on behavioral observation (e.g., Arnold et al., 2011; Walden et al., 2012), many have not concurrently measured emotional reactivity and regulation. This lack of concurrency is particularly noticeable regarding psychophysiological studies of childhood stuttering and emotion. Filling this gap in our knowledge base, at least in part, motivated the present study.

Psychophysiological Measures of Emotion

As the above suggests, a partial picture has emerged regarding the association between emotion and stuttering, an observation particularly true with regard to physiological aspects of emotion. In essence, psychophysiological indices of emotion have received the least empirical attention relative to young CWS, yet early findings of the parasympathetic nervous system (e.g., Jones et al., 2011) suggest that this is a fruitful area of investigation. One means to continue as well as extend this line of research would be to assess sympathetic activity concurrently with parasympathetic activity (e.g., El-Sheikh et al., 2009). Such an approach would contribute to a more comprehensive picture of CWS's autonomic nervous system (ANS) activity, and hopefully further our understanding of how these emotion-related activities/events are associated with childhood stuttering. Prior to further discussion of psychophysiological study of emotions, a brief overview of the ANS seems warranted.

Autonomic nervous system

The main function of the ANS is to maintain homeostasis (i.e., an optimal or ideal physiological and emotional balance), and in doing regulates and coordinates many bodily activities such as digestion, body temperature, blood pressure and is associated with aspects of emotional behavior (Andreassi, 2000, p 35). The ANS innervates smooth muscles, cardiac muscles, and glandular muscles, and is comprised of two branches: 1) parasympathetic and 2) sympathetic. In general, the parasympathetic branch is thought to foster calm physiological states that promote growth, restoration, and repair (Andreassi, 2000, p 37), which some researchers have associated with social communication (Porges, 2007). In contrast, sympathetic nervous system activity is associated with "fight-flight" or "mobilization behaviors," and is typically activated during periods of stress or challenge (Porges, 2007). It had long been believed that ANS activity was under unconscious control and "ran in the background", however, research has shown that self-regulation of physiological processes is possible (e.g., Klimenko, Vovk, Yakovlev, Burmistrov, & Litke, 2007; Patel, 1973). For example, Klimenko et al. (2007) reported that adults were able to increase heart rate variability (i.e., parasympathetic activity) by using external biofeedback of heart rate activity. Typically, psychophysiological studies of ANS activity have focused on either parasympathetic or sympathetic behavior with lesser focus on concurrent assessment of both branches of the ANS.

Parasympathetic nervous system (one associate of emotion regulation)

As mentioned above, findings of Jones et al. (2011) indicate that respiratory sinus arrhythmia (RSA; i.e., the periodic fluctuations in heart rate associated with spontaneous respiration) seems to be one salient psychophysiological associate of emotion in children. Indeed, RSA has been shown to be a reliable measure of parasympathetic influence on the heart (Porges, Doussard-Roosevelt, Portales, & Greenspan, 1996), and is theorized to represent widespread parasympathetic regulation originating from higher levels (i.e., corticobulbar tract, Porges, 2001; Porges, 2007). Baseline RSA reflects resting levels of parasympathetic influence on the heart, and is theorized to represent an individual's ability to sustain attention, engage in social communication, and potential for emotion regulation (Porges, 2007). Changes in RSA from baseline can be used to represent emotional responding to a variety of situations (e.g., Graziano, Keane, & Calkins, 2007; Porges et al., 1996). The regulation of the vagal input on the heart has been likened to a "brake" that can engage or disengage to produce rapid changes in cardiovascular output to meet environmental demands (Porges et al., 1996). In his Polyvagal Theory, Porges (2007) suggests that physiological resources are allocated to fight-flight responses during stressful challenge (i.e., RSA decreases) or to communication during social situations (i.e., RSA increases). Specifically, during stressful or challenging situations, the vagal "brake" is thought to be released to allow heart rate to rise (i.e., RSA decreases), which "mobilizes" physiological and attentional resources for fight-flight behaviors (i.e., "mobilization system," Porges, 2007; 1995). However, during social communication, *increases* in RSA support the allocation of physiological and attentional resources toward facial expression, vocalization, and listening (i.e., "social communication system," Porges, 2007).

With regard to preschool-age children, measures of baseline RSA and change of RSA in response to challenge appear to be fairly stable over time and predictive of future development (e.g., Calkins & Keane, 2004; Porges, Doussard-Roosevelt, Portales, Suess, 1994; Porges et al., 1996). Children with higher baseline RSA display more positive affect (Calkins, 1997), are less at risk for behavior problems (Calkins & Dedmon, 2000), and display higher social competence (Blair & Peters, 2003). In addition, preschool-age children who display high RSA suppression (i.e., decrease of RSA) in response to challenge are less emotionally negative, exhibit fewer behavior problems, and better social skills (Calkins & Keane, 2004). Children with higher RSA suppression have also been shown to exhibit more behavioral emotion regulation (Calkins, 1997; Gentzler et al., 2009), and less risk for externalizing behavior problems (Calkins & Dedmon, 2000; Calkins, Graziano, & Keane, 2007).

Furthermore, significant *decrease* in RSA (i.e., higher RSA suppression) has been reported in response to environmental stressors such as tasks involving cognitive, attentional, physical, behavioral, or emotional challenge (Bar-Haim, Fox, VanMeenen, & Marshall, 2004; Gilissen, Koolstra, Ijzendoom, Bakermans-Kraneenburg, & van der Veer, 2007; Gentzler, Santucci, Kovacs, & Fox, 2009; Heilman et al., 2008; Suess, Porges, Plude, 1994; Weber, ver der Molen, & Molenaar, 1994). Specifically, Bar-Haim et al. (2004) found that children who displayed a greater *decrease* of RSA in response to emotional and cognitive challenge narrative performance produced more coherent and adaptive narratives. In addition, researchers have reported *decreases* of RSA in response to fear-inducing film stimuli (Gilissen et al., 2007), physical challenge (Heilman et al., 2008), and sustained attention tasks (Suess et al., 1994, Weber et al., 1994). On the other hand, Heilman et al. (2008) found that children's RSA *increased* during a challenging social situation (hearing evaluations with a stranger and no parent present).

In summary, the ability to appropriately (dis)engage vagal influence on the heart in response to environmental conditions is thought to facilitate adaptive responding, be it social communication or responsiveness to challenging situations. Thus, findings from numerous empirical studies suggest that RSA, as a measure of parasympathetic influence on the heart, appears to be an informative associate of emotional *regulation* as well as physiological preparedness for and responsiveness to environmental challenge.

Sympathetic nervous system (one associate of emotional reactivity)

Among various physiological processes, the sympathetic nervous system exclusively regulates *skin conductance* (i.e., electrodermal activity of the sweat glands; Boucsein, 1992), making it a viable measure to concurrently study with RSA (i.e., parasympathetic activity) to develop a comprehensive account of autonomic activity. Two measures of skin conductance level (SCL) are typically reported: baseline SCL values and changes in SCL. Baseline values of SCL refer to resting levels of sympathetic nervous system activity. Changes in SCL from baseline can be used to measure sympathetic activation in response to stressful conditions, for example, when physiological resources are shifted toward fight-flight behaviors (Boucsein, 1992). Researchers commonly use SCL to measure sympathetic responses during exposure to a variety of tasks and/or stimuli (e.g., tasks involving emotional challenge), and SCL has been shown to be associated with emotional reactivity, fear or stress (e.g., Cole, Zahn-Waxler, Fox, Usher, & Welsh, 1996; Fabes, Eisenberg, Eisenbud, 1993; Fabes, Eisenberg, Karbon, Bernzweig, & Speer, 1994; Fowles, Kochanska, & Murray, 2000; Gilissen et al., 2007).

Relative to preschool-age children, Cole et al. (1996) found that preschool-age children that display “modulated” emotional expression (i.e., responsivity without intense display) exhibited lower baseline SCL compared to children that were highly expressive (negative emotion) and inexpressive (no emotion displayed). Furthermore, Cole et al.

(1996) also reported that highly expressive children displayed greater increase in skin conductance than inexpressive children during negative mood induction. Similarly, Gilissen et al. (2007) found that temperamentally fearful four-year-old children with less harmonious relationships with their parents displayed greater SCL increase in response to fear-inducing film clips. Furthermore, Fabes et al. (1994) found that for kindergarten children skin conductance was positively related to facial distress and inversely related to helpfulness. These results are consistent with Fowles et al. (2000) findings that temperament dimensions of fearfulness and effortful (or inhibitory) control were positively correlated with SCL for four-year-old children. Lastly, and with slightly older children (7 years old), Gilissen et al. (2008), reported that children with insecure attachment representation display higher SCL reactivity during a stressful social speaking task than controls.

In summary, as a measure of sympathetic activity, SCL appears to be a useful measure of physiological associates of emotional *reactivity*, fear, or stress in response to a variety of situations (i.e., emotional challenge) that varies based upon aspects of emotional development (i.e., parent-child relationship, emotional responses, temperamental dimensions).

Interactions of parasympathetic and sympathetic activity

The above review suggests that parasympathetic and sympathetic activity is importantly related to typical emotion development, as well as response to stressors in the environment. It should be noted, however, that not only does each system perform separately, but often they act concurrently. To account for such interactions, Berntson, Cacioppo, and Quigley (1991) proposed the *doctrine of autonomic space*. This two-dimensional model of parasympathetic and sympathetic activity suggests that parasympathetic and sympathetic activity can be reciprocal or nonreciprocal on a given target organ (e.g., the heart).

As shown in Table 1, reciprocal *sympathetic* activation is characterized by sympathetic activation and parasympathetic inhibition. In contrast, reciprocal *parasympathetic* activation is characterized by sympathetic inhibition and parasympathetic activation (Berntson et al., 1991). As Table 1 further indicates, nonreciprocal activation can be characterized by *coactivation* or *coinhibition* of both sympathetic and parasympathetic systems simultaneously. Furthermore, it is possible for one system to activate with no concurrent change in the other system (e.g., sympathetic activation with no change in parasympathetic activity).

Table 1

Response patterns of autonomic nervous system as described Berntson et al. (1991).

Autonomic response patterns

	Parasympathetic response	
Sympathetic response	***Increase***	***Decrease***
Increase	*Response*: Coactivation (non reciprocal) *Function*: Ambivalent, opposing action	*Response*: Reciprocal Sympathetic *Function*: Adaptive stress response
Decrease	*Response*: Reciprocal Parasympathetic *Function*: Adaptive calming response	*Response*: Coinhibition (non reciprocal) *Function*: Ambivalent, opposing action

Although there are at least nine possible interactions of sympathetic and parasympathetic response patterns, we will focus on the four patterns of autonomic activity that seem to have the most saliency for the present study: (1) reciprocal sympathetic activation, thought to be an adaptive response to a stressor; (2) reciprocal parasympathetic activation, thought to be appropriate for situations where calm physiological states are more adaptive; (3) nonreciprocal coactivation; and (4) nonreciprocal coinhibition. The latter patterns of autonomic activity — (3) and (4) — are thought to be more ambivalent autonomic response and likely to result in little or no change in the autonomic system if sympathetic and parasympathetic activation is reasonably equivalent (Berntson et al., 1991).

As an empirical exemplar of such perspectives on ANS activity, El-Sheik et al (2009) studied SCL and RSA simultaneously in children. They reported that their measure of sympathetic activation (i.e., SCL) operated similar to a measure of sympathetic influence on the heart (i.e., preejection period) and in combination with parasympathetic activity (i.e., RSA) predicted child behavior. Their findings point out the feasibility and importance of concurrently studying RSA and SCL at baseline and in response to stress when attempting to gain the most comprehensive account of psychophysiological associates of stuttering.

The Present Study

As mentioned above, and as Beauchaine (2001) suggests, sympathetic and parasympathetic activity should be considered simultaneously in order to best understand the integrated functioning of the autonomic nervous system relative to behavioral and psychological processes. To date, to this writer's knowledge such an approach has not yet been employed with preschool-age CWS. Therefore, it was the purpose of the current study to replicate and extend the findings of Jones et al. (2011). In doing so, the present writer tried to elaborate on previous findings from caregiver reports and behavioral observations regarding emotional contributions to stuttering in attempts to develop a more comprehensive understanding of the integrated functioning of autonomic activity in preschool-age CWS.

Specifically, it was thought that baseline indices of autonomic activity (i.e., baseline RSA and baseline SCL) could provide psychophysiological context for findings from caregiver reports that CWS, when compared to CWNS, display stable proclivities toward greater reactivity (e.g., Eggers et al., 2010; Karrass et al., 2006) and poorer regulatory skills (e.g., Anderson et al., 2003; Eggers et al., 2010; Felsenfeld et al., 2010; Karrass et al., 2006). Similarly, RSA and SCL response patterns during emotional challenge would provide psychophysiological context for behavioral observations that CWS, when compared to CWNS, exhibit less adaptive responding to challenging emotional situations (e.g., Johnson et al., 2010; Schwenk et al., 2007). If true, these findings would provide empirical support for speculation that various aspects of emotional processes, including psychophysiological processes, are associated with childhood stuttering (Conture & Walden, 2012).

Of particular salience to the present study, are reported behavioral observations that (a) increases in preschool-age CWS's stuttering are related to decreased duration and frequency of emotion *regulatory* strategies (Arnold et al., 2011) and (b) increased emotional arousal/reactivity that may be associated with decreased emotion *regulation*

(Walden et al., 2012). If overt behavioral aspects of emotion *reactivity* and *regulation* are associated with changes in children's stuttering, the same might be true psychophysiologically. The present writer speculated that preschool-age CWS would display relatively *maladaptive* sympathetic (i.e., SCL) and parasympathetic (i.e., RSA) activity that may be related to diffuse or generalized differences in their *reactivity* and *regulation* of non-cardiac processes. Furthermore, these differences may be associated with difficulties in fluently initiating and/or maintaining speech-language production. This evidence should help further empirically assess the role of emotion *reactivity* and *regulation* in childhood stuttering.

Therefore, the present study addressed the general issue of whether parasympathetic regulation, as indexed by RSA and RSA change from baseline (RSA-change) as well as sympathetic reactivity, as indexed by SCL and SCL change from baseline (SCL-change), are associated with childhood stuttering. Specifically, this study was designed to assess between-group differences in psychophysiological reactivity and regulation across two distinct tasks: (1) listening-viewing (emotionally-arousing conditions) and (2) speaking (narrative tasks). For each of these specific issues listed below we evaluated sympathetic and parasympathetic functioning for both groups separately as well as concurrently. It was expected that CWNS would display reciprocal parasympathetic activation (i.e., parasympathetic increase and sympathetic decrease) during baseline and speaking conditions and reciprocal sympathetic activation (i.e., parasympathetic decrease and sympathetic increase) during emotional challenge conditions. On the other hand, it was expected that CWS would display less adaptive response patterns, perhaps reciprocal sympathetic activation or nonreciprocal activation (i.e. coactivation or coinhibition) during baseline, emotion challenge, and speaking conditions.

This investigation addressed four specific issues. First, to determine preschoolers' *physiological reactivity* and *regulation*, baseline RSA[2] and SCL were assessed. It was hypothesized that preschool-age CWS, compared to CWNS, would exhibit significantly *lower* RSA and *greater* SCL at baseline (i.e., reciprocal sympathetic activation). Second, to determine these children's *physiological reactivity* and *regulation during listening-viewing*, the RSA and SCL of preschool-age CWS and CWNS was assessed during emotionally arousing listening-viewing conditions (i.e., positive and negative). It was hypothesized that CWS, compared to CWNS, would exhibit significantly *lower* RSA and *greater* SCL during the emotion challenge tasks (i.e., reciprocal sympathetic activation). Third, to assess preschool-age children's *physiological reactivity* and *regulation during speaking*, RSA and SCL were measured during narrative (speaking) tasks. It was hypothesized that CWS, compared to CWNS, would display significantly *lower* RSA and *greater* SCL during the speaking tasks (i.e., reciprocal sympathetic activation). Fourth, to assess preschooler's *physiological response to environment*, RSA-change and SCL-change were measured as indexes of response magnitude (i.e., reactivity) to listening-viewing (emotionally arousing stimuli) and to speaking (narrative task). It was hypothesized that preschool-age CWS, when compared to CWNS, would exhibit *less*

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[2] This and subsequent hypotheses are theory driven. However, as typical, when measuring RSA, heart period (HP) is also collected as an overall measure of cardiac function for comparison purposes. As heart period deviates from RSA, it reflects alternative influences on heart rate, such as sympathetic, intrinsic, nonmyelinated vagal, and neuroendocrine factors (Doussard-Roosevelt, Montgomery, & Porges, 2003). No hypotheses were generated relative to HP.

adaptive patterns of RSA-change and SCL-change to listening-viewing and speaking conditions (i.e., nonreciprocal or reciprocal sympathetic activation).

CHAPTER II

METHOD

Participants and Procedure

Participants

Participants included 20 CWS (15 male) and 21 CWNS (11 male) between the preschool-ages of 37 and 59 months. CWS' chronological age (*M* = 48.55, *SD* = 10.84) was not significantly different from that of CWNS (*M* = 48.10, *SD* = 10.17). All participants scored at or above the 16th percentile on a series of standardized speech and language tests, including the Goldman Fristoe Test of Articulation (GFTA; Goldman & Fristoe, 2000), Peabody Picture Vocabulary Test (PPVT-III; Dunn & Dunn, 1997), the Expressive Vocabulary Test (EVT-2; Williams, 1997), and the Test of Early Language Development (TELD-3; Hresko, Reid, Hammill, & Pro-Ed (Firm), 1999). Socioeconomic status (SES) was determined by scoring parent education and occupation levels on a 7-point scale, taken from Hollingshead (1975). One-way analysis of variance (ANOVA) with talker group (i.e., CWS vs. CWNS) as the factor compared the two talker groups on standardized tests of speech-language abilities and SES. There were no significant differences between the two talker groups on measures of speech-language abilities or SES with the largest effect size (for TELD-3 receptive standard score) being .07.

The participant's race was obtained via caregiver interview. CWS participants were 18 Caucasians, 1 African-American, and 1 more than one reported race. CWNS participants were 18 Caucasians, and 3 more than one reported race.

To be considered as a CWS, a child had to exhibit 3 or more stutterings (i.e., sound syllable repetitions, monosyllabic whole-word repetitions and sound prolongations) per 100 words and receive an overall score of 11 or higher on the third edition of the Stuttering Severity Instrument (SSI-3; Riley, 1994). To be considered a CWNS, a child had to exhibit 2 or fewer stutterings per 100 words of conversational speech, and receive an overall score of 10 or below on the SSI-3. No CWS received or was receiving treatment for stuttering. The Vanderbilt University IRB approved the protocol. Informed consent by parents and assent by children was obtained.

From the initial pool of participants for whom data was collected, 1 was excluded because talker group classification was undeterminable. Twelve other participants (7 CWS and 5 CWNS) were excluded because it was not possible to acquire RSA and/or SCL data due to non-compliance and/or their data contained too much artifact.

Procedure

Upon arrival at the Vanderbilt Developmental Stuttering Laboratory, participants were led into a room and seated in a car safety seat situated directly in front of a computer monitor. After allowing each participant a few minutes to become acclimated to the environment, participants were prepared for data acquisition. To begin, each participant's skin was wiped clean with an alcohol pad for those areas where electrodes were to be placed to maximize electrical conductance. Next hypoallergenic electrodes were applied to the skin surface at the jugular notch at the superior position of the rib cage and at the base of the rib cage on the left hand side of the torso for collection of RSA data, and on the index and ring fingers of the right hand for collection of SCL data.

A lapel microphone was placed on the participant's clothing near their mouth, and a table microphone was placed directly in front of each participant.

For the pre- and post-experimental baseline conditions, participants viewed an animated screensaver of a three-dimensional fish tank for approximately four minutes. This screensaver contained minimal action and therefore was assumed to be suitable to establish a baseline level of RSA and SCL activity. This screensaver was viewed twice (once at beginning and once at ending of experiment) to obtain both pre- and post-baselines measures.

After the pre-experimental baseline, participants were presented with negative and positive audio/video clips taken from one of five g-rated movies, including Snow White, The Lion King, The Little Mermaid, The Wizard of Oz, and The Princess and the Frog. These video clips, each approximately four minutes in duration, were intended to elicit negative and positive affective states, with their order of presentation counterbalanced. After the first baseline and each of the two film clips, a speaking task was performed, in which participants were asked to produce a narrative from one of three storybooks about a boy, a dog, and a frog by the author Mercer Mayer.

Processing of RSA and HP

To obtain RSA, an electrocardiogram (ECG) was acquired for each participant using the Biopac MP150 system (Biopac Systems, Inc.) and digitized at 1250 Hz per channel. The raw ECG was first band-pass filtered to remove high frequency noise and low frequency drift (high pass cutoff: 0.5 Hz; low pass cutoff: 35 Hz). Inter-beat interval

(IBI) series were produced from segments within the ECG corresponding to each baseline, the negative and positive film clips, and the first 4-minutes of all three narrative tasks.

CardioEdit software (Brain-Body Center, University of Illinois at Chicago, 2007) was used to correct any artifacts within the IBI series by adding, dividing, or averaging consecutive points so that they were consistent with surrounding points. CardioBatch software (Brain-Body Center, University of Illinois at Chicago, 2007) was then used to derive measures of RSA from corrected IBI files. RSA was calculated using Porges' methodology (Porges, 1985; Porges & Bohrer, 1990), which uses a 21-point polynomial to detrend periodicities in the IBI series that are slower than RSA (e.g., basic metabolic processes often associated with vasomotor and blood pressure oscillation rather than RSA, for further details, see Lewis, Furman, McCool, & Porges, 2012). A band-pass filter was then applied to the IBI series to extract the variance at the frequency of respiration for young children: 0.24 and 1.04 Hz.

The above process resulted in an approximation or estimate of RSA expressed as the natural log of this variance: $\ln (\mathrm{ms})^2$ (for further details, see Lewis et al., 2012). Values of RSA and HP were derived for sequential 30-second epochs within each 4-minute condition. It should be noted that baseline RSA and HP values could influence RSA and HP change from baseline (law of initial values). Therefore, in order to remove any relation between change and initial status, RSA change from baseline (RSA-change) and HP change from baseline (HP-change) were computed as residualized change scores (obtained through regressing baseline RSA/HP on RSA/HP during the subsequent challenge tasks).

Processing of SCL

The SCL signal was acquired using the Biopac MP150 system (Biopac Systems, Inc.) and digitized at 1250 Hz. The “Connect Endpoints” math function of the Biopac Acknowledge 4.1 software was then used to correct any missing data artifacts acquired from the removal of the electrodes during data collection. No more than five percent of the total data for any one epoch was corrected using this procedure. Text files were then created for each epoch of SCL data, and the data was then downsampled to 125 Hz by retaining every 10th data point for each epoch. From the downsampled data, a mean SCL value for the epoch was derived (after phasic responses were removed from the signal) and expressed in microSiemens (μS). Values of SCL were derived for sequential 30-second epochs within each 4-minute condition. As with RSA, baseline SCL values could influence SCL-change (law of initial values). Therefore, in order to remove any relation between change and initial status, SCL-change was computed as a residualized change score (obtained through regressing baseline SCL on SCL during the subsequent challenge tasks).

Measurement reliability

To assess measurement reliability, 20% of the total final data corpus was randomly selected and used to determine inter-judge reliability between the present writer and trained researchers (graduate-level or above) for the measures of (a) RSA, (b) HP[3], and (c) SCL.

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[3] Again, it will be recalled that heart period (HP) in this area of endeavor is collected for comparison purposes. Hence, both measurement reliability and analytical models for HP

Values of RSA for the two researchers were within 0.10 ln $(ms)^2$ for listening-viewing (i.e., including pre- and post-baseline, negative and positive film clips) and speaking (i.e., including all three narrative tasks) tasks, with correlations of RSA values between the two researchers exceeding 0.99 for both. It should be noted that for all IBI files no more than a maximum 5% of points were corrected before that data was not included in the final data corpus. Correlations between the two researchers for values of HP exceeded 0.99 for listening-viewing and speaking tasks.

A second researcher independently derived values of SCL, and the values of SCL for the two researchers were within 0.10 microSiemens (µS) for all listening-viewing and speaking tasks. Inter-judge correlations exceeded 0.99 for both. No more than 5% of data points were corrected for each participant.

Although not a dependent measure of the present study, speech-language pathologists collected all speech fluency data for talker group classification. Inter-judge correlations for stuttered disfluencies ranged from .756 - .959 and total disfluencies ranged from .792 - .962.

Data Analysis

Statistical modeling

Linear mixed-effects models (Pinheiro & Bates, 2000) were used to examine each of the four hypotheses. The linear mixed-effects models were run using Statistical Package for the Social Sciences Statistics version 20 (SPSS Statistics). Twelve separate

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will be performed, but mainly for descriptive purposes rather than to address theory-driven hypotheses.

models[4] were constructed to examine the dependent measures (i.e., RSA, HP, SCL) across the seven conditions (i.e., pre- and post-baselines, two film clips, and three narrative tasks) and between the two talker groups (i.e., CWS and CWNS). The values derived from each of the 30-second epochs were used as repeated measures in RSA, HP, and SCL models to assess between-group differences. Residual change from baseline to challenge conditions were used as repeated measure in separate RSA-change, HP-change, and SCL-change models to assess physiological responses to environmental conditions (i.e., listening-viewing tasks vs. speaking tasks). To reduce problems with multiple significance tests, only results for the four a priori hypotheses are discussed.

Fixed factors and continuous covariates

These statistical models included fixed factors and continuous covariates reflecting potential alternative explanations for the observed behavior of RSA, HP, and SCL. Four *fixed factors* were covaried in each RSA, HP, and SCL model: condition (pre/post-baseline, negative/positive conditions for listening-viewing; pre-baseline/negative/positive prior manipulations for speaking), film (Lion King, The Wizard of OZ, The Little Mermaid, or Happy Feet), order (positive film first vs. negative film first), and gender. In addition, three *continuous covariates* were included in each RSA and HP model, age in months, body mass index (BMI), and an estimate of respiration[5] rate (with the latter variables known to impact RSA, El-Sheikh, 2005; El-

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[4] Four models of RSA and four models of SC were used to assess the theoretically-driven hypotheses, and four similarly specified models of HP were used for comparison.

[5] A custom program, RespFreqFromRSA (Lewis, 2010), developed in MATLAB (r2012a) was used to extract the respiration rate from the frequency of the RSA rhythm. It has previously been demonstrated that the convergence between the dominant

Sheikh, Erath & Keller, 2007; Reilly & Moore, 2003). In order to assess the impact of amount of talking on the dependent measures of interest, number of utterances were covaried in each of the speaking models. Similarly to Buhr, Conture, Kelly, and Jones' (2011) study that used computer-based transcriptions (SALT, Systematic Analysis of Language Transcripts; Miller & Iglesias, 2008) to analyze the narrative transcripts of preschool-age CWS, utterance segmentation were based on either 1) a new independent clause or 2) a pause of more than 1 second. Furthermore, SCL was entered as a covariate (i.e., to evaluate the relation between RSA and SCL) along with the interaction of group and SCL (i.e., to evaluate whether the relation between RSA and SCL differs between the groups) in each RSA model. When non-significant, this interaction (i.e., group by SCL) and other interactions (e.g., group by condition) were removed from the statistical models. In the models assessing physiological reactivity and regulation during emotion (hypothesis 2) and speaking (hypothesis 3) conditions, baseline values of RSA, HP and SCL were included to account for the initial value of those variables. Table 2 lists the proposed parameters of the linear mixed-effects models to be employed in this study. For each term in the model, Cohen's *d* as a measure of effect size was calculated using approximate effect sizes from Type III[6] *F* ratios based on meta-analytic formulas (Rosenthal & DiMatteo, 2001).

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frequency in the RSA component of the heart period time series is a robust estimate of the spontaneous breathing rate (Denver, Reed, & Porges, 2007).

[6] Type III tests examine the significance of each effect at the same time (rather than sequentially) as all other effects in the model (Littell, Milliken et al., 2006).

Table 2

Parameters of the linear mixed-effects models.

Dependent variables	***Conditions***
• Respiratory sinus arrhythmia (RSA) • RSA change from baseline (RSA-change) • Skin conductance level (SCL) • Skin conductance change (SCL-change)	• Emotion conditions o Pre-baseline o Positive o Negative o Post-baseline • Narration Conditions o Narrative one (follows pre-baseline) o Narrative two (follows positive or negative condition) o Narrative three (follows positive or negative condition)
Covariates	***Fixed factors***
• Age (in months) • Body mass index (BMI) • Respiration • Number of utterances • SCL (in RSA models to assess relation of RSA and SCL) • Baseline RSA • Baseline SCL	• Talker group o Children who stutter (CWS) o Children who do not stutter (CWNS) • Task (Listening-viewing versus speaking) • Order (i.e., negative first or positive first) • Gender • Film • Prior film clip (in narrative models only) • Condition (in listening-viewing models only)
Interactions	
• Group by SCL (in relation of RSA and SCL model) • Group by condition (in RSA and SCL models) • Group by prior film clip (in narrative models of RSA and SCL models) • Group by task (i.e., listening-viewing versus speaking; in RSA-change and SCL-change models)	

Hypothesis 1: Physiological reactivity and regulation at baseline

To assess preschooler's *physiological regulation during* ***baseline conditions,*** a linear mixed-effects model with the interaction of group and condition was used to examine baseline RSA and SCL (i.e., RSA/SCL at pre-baseline and post-baseline).

Hypothesis 2: Physiological reactivity and regulation during listening-viewing

To assess preschool's *physiological reactivity* and *regulation during* ***listening-viewing***, a linear mixed-effects model with the interaction of group and condition was used to examine RSA and SCL during the emotionally arousing listening-viewing conditions (i.e., positive and negative).

Hypothesis 3: Physiological reactivity and regulation during speaking

To assess preschoolers' *physiological reactivity* and *regulation during* ***speaking,*** a linear mixed-effects model with the interaction of group and prior listening-viewing condition (i.e., pre-baseline, negative, positive) was used to examine RSA during the social-communicative narrative tasks.

Hypothesis 4: Physiological response to environment

To assess preschooler's *physiological response to* ***environmental change***, a linear mixed-effects models with the interaction of task (listening-viewing vs. speaking) and talker group was used to examine RSA-change and SCL-change during the listening-viewing tasks (emotionally arousing stimuli) compared to the speaking (narrative) tasks.

CHAPTER III

RESULTS

Descriptive Information

Speech fluency

One-way analysis of variance (ANOVA) with talker group (i.e., CWS vs. CWNS) as the factor compared the two talker groups on measures of speech disfluency. As would be expected based on participant classification criteria, there was a significant difference in *stuttered disfluencies* per 100 words between CWS ($M = 8.99$, $SD = 5.43$) and CWNS ($M = 1.08$, $SD = 0.78$), $F(1, 39) = 43.69$, $p < .001$, $\eta^2 = .528$ as well as a significant difference between *SSI-3 scores* for CWS ($M = 18.50$, $SD = 5.84$) and CWNS ($M = 6.29$, $SD = 1.71$), $F(1, 39) = 84.51$, $p < .001$, $\eta^2 = .684$. Also, as would be expected, there was a significant difference between CWS ($M = 13.53$, $SD = 4.47$) and CWNS ($M = 5.05$, $SD = 2.88$), $F(1, 39) = 52.65$, $p < .001$, $\eta^2 = .574$ in *total* disfluencies per 100 words. However, there was no significant difference between CWS ($M = 4.54$, $SD = 2.97$) and CWNS ($M = 3.97$, $SD = 2.74$) in *non-stuttered disfluencies* per 100 words.

Physiological Reactivity and Regulation

Results pertaining to the four a priori hypotheses are presented as follows: (1) between-group differences during *baseline* conditions (Hypothesis 1), (2) between-group differences during emotionally-arousing *listening-viewing* conditions (Hypothesis 2), (3) between-group differences during *narrative* (speaking) tasks (Hypothesis 3), and (4) between-group differences in *changes of physiological response* to environmental conditions (i.e., listening-viewing vs. speaking) (Hypothesis 4).

Each of these prose sections of Results is associated with two tables, one containing descriptive statistics (i.e., mean, standard deviation and range) and the other inferential findings pertinent to each hypothesis. Also, within each of these sections only statistical details pertaining to significant findings are reported. Mean values for each of the dependent measures (RSA, SCL, HP) are presented for all individual participants in Appendix B.

Physiological reactivity and regulation: Baseline conditions (Hypothesis 1)

Descriptive statistics pertaining to Hypothesis 1 are presented in Table 3. To test Hypothesis 1, that is, preschool-age CWS, compared to CWNS, exhibit greater SCL and lower RSA at baseline, inferential analyses were performed, with results depicted in Table 4.

Table 3

*Descriptive statistics pertaining to Hypothesis 1 (i.e., **baseline** conditions) for preschool-age children who stutter (CWS, n=20, 15 male) and children who do not stutter (CWNS, n = 21, 11 male).*

	Respiratory Sinus Arrhythmia		**Skin Conductance Level**	
CWS	*M (SD)*	*Range*	*M (SD)*	*Range*
Pre-baseline	6.02 (1.26)	4.13-8.45	10.71 (7.13)	1.91-29.02
Post-baseline	5.81 (1.32)	3.54-8.56	19.78 (10.49)	3.08-38.69
CWNS	*M (SD)*	*Range*	*M (SD)*	*Range*
Pre-baseline	6.72 (.88)	5.45-8.63	9.90 (5.51)	1.87-22.59
Post-baseline	6.43 (.96)	4.78-7.93	17.53 (7.84)	4.83-39.92

Table 4

Inferential analyses (i.e., linear mixed-effects statistical models, Pinheiro & Bates, 2000) pertaining to Hypothesis 1 (i.e., ***baseline*** *conditions) for respiratory sinus arrhythmia and skin conductance level for preschool-age children who stutter (CWS, n = 20, 15 male) and preschool-age children who do not stutter (CWNS, n = 21, 11 male).*

	Baseline Conditions			
	Respiratory Sinus Arrhythmia		*Skin Conductance Level*	
Effect	*p* (sig.)	*d*	*p* (sig.)	*d*
Group	**0.045**	0.62	0.586	0.19
Group*Condition	0.59*	0.06	0.084*	0.14*
Group*task (listening-viewing verus speaking)	-	-	-	-
Group*Prior Condition	-	-	-	-
Group*SCL	0.97*	0.005	-	-
Respiratory sinus arrthymia	-	-	**0.028**	0.18
Skin conductance level (SCL)	0.19	0.17	-	-
Condition	0.29	0.11	**<0.001**	2.08
Prior manipulation	-	-	-	-
Task (listening-viewing versus speaking)	-	-	-	-
Gender	0.43	0.23	0.43	0.28
Body mass index (BMI)	**0.03**	0.63	**-**	-
Respiration	**0.004**	0.48	**-**	-
Age	0.69	0.12	0.14	0.53
Film	0.26	0.34	0.74	0.25
Film order	0.34	0.28	0.53	0.22

Notes. Only results applicable to the a priori hypothesis appear boxed, with significant findings **bolded**, and measures of effect size reported as Cohen's *d* (Cohen, 1992). *Indicates interaction effects that were initially included in statistical models, but removed when non-significant. "-" Indicates that the measure was not applicable to a particular analysis, and thus, not included in the statistical model.

Skin conductance level (SCL), an index of physiological *reactivity,* was measured during both pre- and post-baseline conditions. There was no significant between-group difference for SCL at baseline.

Respiratory sinus arrhythmia (RSA), an index of physiological *regulation*, was assessed at the baseline conditions. As shown in Figure 1, during the baseline conditions CWS (*estimated marginal mean, EMM* = 5.958, *standard error, SE* = .188) displayed significantly lower RSA amplitude than CWNS (*EMM* = 6.482, *SE* = .169), *F* (1, 44.83) = 4.25, *p* = .045, *d*[7] = .62.

There was neither a significant relation between SCL and RSA, nor was there a different relation between CWS and CWNS for these variables during baseline conditions.

The significant between-group difference in RSA at baseline supported Hypothesis 1; however, null findings for SCL and the relation between RSA and SCL between the groups did not support Hypothesis 1.

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[7] According to Cohen's (1992) guidelines, Cohen's *d* effect size values of .2/.5.8 may be considered small/medium/large.

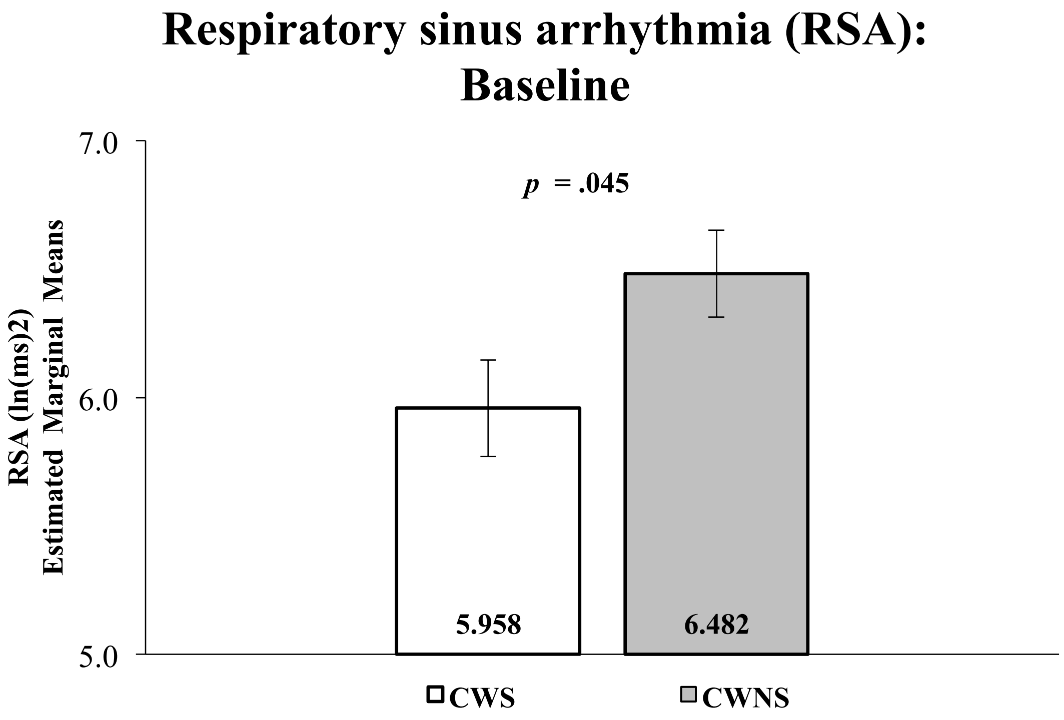

Figure 1. Respiratory sinus arrhythmia (RSA) at baseline for preschool-age CWS (n = 20, 15 male) and CWNS (n = 21, 11 male) (± standard error). Values at the base of each column = RSA estimated marginal mean for each talker group. Ln $(ms)^2$ = natural log of RSA estimate (for further detail, see Lewis et al., 2012).

Physiological reactivity and regulation: Listening-Viewing Conditions (Hypothesis 2)

Descriptive statistics pertaining to Hypothesis 2 are presented in Table 5. To test Hypothesis 2, that is, preschool-age CWS, compared to CWNS, exhibit greater SCL and lower RSA during emotionally-challenging listening-viewing tasks, inferential analyses were performed, with results depicted in Table 6.

Table 5

Descriptive statistics pertaining to Hypothesis 2 (i.e., ***emotion*** *conditions) for preschool-age children who stutter (CWS, n=20, 15 male) and children who do not stutter (CWNS, n = 21, 11 male).*

	Respiratory Sinus Arrhythmia		**Skin Conductance Level**	
CWS	*M (SD)*	*Range*	*M (SD)*	*Range*
Negative	6.06 (1.41)	3.85-9.01	17.12 (10.05)	3.71-37.45
Positive	6.04 (1.54)	3.32-8.63	18.22 (10.24)	4.36-38.47
CWNS	*M (SD)*	*Range*	*M (SD)*	*Range*
Negative	6.47 (.90)	5.20-8.30	15.50 (7.14)	4.56-37.83
Positive	6.66 (.84)	5.44-8.18	14.63 (6.19)	5.06-30.90

Table 6

*Inferential analyses (i.e., linear mixed-effects statistical models, Pinheiro & Bates, 2000) pertaining to Hypothesis 2 (i.e., positive and negative **listening-viewing** conditions) for respiratory sinus arrhythmia and skin conductance level for preschool-age children who stutter (CWS, n = 20, 15 male) and preschool-age children who do not stutter (CWNS, n = 21, 11 male).*

	Listening-Viewing Conditions			
	Respiratory Sinus Arrhythmia		*Skin Conductance Level*	
Effect	*p* (sig.)	*d*	*p* (sig.)	*d*
Group	0.24	0.31	0.37	0.32
Group*Condition	0.45*	0.08	**0.023**	0.19
Group*SCL	0.22*	0.24	-	-
Respiratory sinus *arrhythmia*	-	-	**0.035**	0.18
Skin conductance level (SCL)	0.21	0.26	-	-
Condition	0.91	0.01	0.96	0.003
Gender	0.56	0.15	0.86	0.06
Body mass index (BMI)	0.81	0.06	**-**	-
Respiration	**<0.001**	0.71	**-**	-
Age	0.17	0.36	0.83	0.08
Film	0.16	0.34	0.16	0.46
Film order	0.35	0.25	0.54	0.28
Baseline RSA	**<0.001**	3.46	-	-
Baseline SCL	-	-	**<0.001**	2.90

Notes. Only results applicable to the a priori hypothesis appear boxed, with significant findings **bolded**, and measures of effect size reported as Cohen's *d* (Cohen, 1992). *Indicates interaction effects that were initially included in statistical models, but removed when non-significant. "-" Indicates that the measure was not applicable to a particular analysis, and thus, not included in the statistical model.

Skin conductance level (SCL) was measured during the negative and positive emotionally-arousing listening-viewing conditions. There was no significant between-group difference for SCL during the emotionally-arousing listening-viewing conditions. However, there was a significant group by condition interaction for SCL, *F* (1, 572.51) = 5.204, *p* =.023, *d* = .19. Follow-up inferential statistical analysis indicated no significant group by condition differences. Descriptively, however, CWS exhibited greater SCL during the positive listening-viewing condition, whereas CWNS exhibited greater SCL during the negative listening-viewing condition.

Respiratory sinus arrhythmia (RSA) was assessed during the positive and negative emotionally-arousing listening-viewing conditions. There was no significant between group difference for RSA or interaction of group and listening-viewing condition.

There was also neither a significant relation between SCL and RSA nor a different relation between CWS and CWNS for these variables during listening-viewing conditions.

The significant between-group interaction effect for SCL partially supported Hypothesis 1, however, null findings for RSA and the relation between RSA and SCL between the groups did not support Hypothesis 1.

Physiological reactivity and regulation: Speaking (Hypothesis 3)

Descriptive statistics pertaining to Hypothesis 3 are presented in Table 7. To test Hypothesis 3, that is, preschool-age CWS, compared to CWNS, exhibit greater SCL and lower RSA during the narrative tasks, inferential analyses were performed, with results depicted in Table 8.

Table 7

Descriptive statistics pertaining to Hypothesis 3 (i.e., speaking conditions) for preschool-age children who stutter (CWS, n=20, 15 male) and children who do not stutter (CWNS, n = 21, 11 male).

	Respiratory Sinus Arrhythmia		**Skin Conductance Level**	
CWS	*M (SD)*	*Range*	*M (SD)*	*Range*
Narrative #1	5.53 (1.27)	3.84-8.28	13.18 (8.12)	1.64-31.73
Narrative #2	5.21 (1.27)	3.08-7.37	17.13 (9.61)	5.33-37.67
Narrative #3	5.24 (1.25)	3.33-7.82	19.52 (10.62)	3.93-37.51
CWNS	*M (SD)*	*Range*	*M (SD)*	*Range*
Narrative #1	6.16 (.78)	4.93-7.62	12.59 (5.27)	3.06-25.09
Narrative #2	5.84 (.70)	4.88-7.18	15.67 (6.76)	4.30-31.02
Narrative #3	5.97 (.71)	4.88-7.39	17.37 (7.02)	5.90-37.32

Table 8

Inferential analyses (i.e., linear mixed-effects statistical models, Pinheiro & Bates, 2000) pertaining to Hypothesis 3 (i.e., ***speaking*** *conditions) for respiratory sinus arrhythmia and skin conductance level for preschool-age children who stutter (CWS, n = 20, 15 male) and preschool-age children who do not stutter (CWNS, n = 21, 11 male).*

	Speaking Conditions			
	Respiratory Sinus Arrhythmia		*Skin Conductance Level*	
Effect	*p* (sig.)	*d*	*p* (sig.)	*d*
Group	0.106	0.27	0.73	0.11
Group*Prior Condition	0.15*	0.20	**0.029**	0.12
Group*SCL	**0.007**	0.45	-	-
Respiratory sinus arrthymia	-	-	0.61	0.03
Skin conductance level (SCL)	**0.038**	0.35	-	-
Prior manipulation	**<0.001**	0.40	**<0.001**	0.57
Gender	**0.003**	0.55	0.66	0.13
Body mass index (BMI)	**0.04**	0.39	-	-
Respiration	0.17	0.19	-	-
Age	**0.003**	0.56	0.76	0.10
Film	**0.038**	0.30	0.44	0.30
Film order	0.22	0.23	0.15	0.45
Baseline RSA	**<0.001**	2.79	-	-
Baseline SCL	-	-	**<0.001**	3.51
Number of Utterances	0.76	0.05	-	-

Notes. Only results applicable to the a priori hypothesis appear boxed, with significant findings **bolded**, and measures of effect size reported as Cohen's *d* (Cohen, 1992). *Indicates interaction effects that were initially included in statistical models, but removed when non-significant. "-" Indicates that the measure was not applicable to a particular analysis, and thus, not included in the statistical model.

Skin conductance level (SCL) was measured during the narrative speaking conditions, each of which was preceded by a listening-viewing condition (pre-baseline, negative, positive). Inferential analysis indicated no significant between-group difference for SCL. However, for SCL there was a significant group by condition (prior listening-viewing condition) interaction, *F* (2, 958.96) = 3.558, *p* =.029, *d* = .12. As shown in Figure 2, further assessment of this interaction (Bonferroni corrected) indicated that CWS exhibited significantly greater SCL during the narrative (speaking) following the positive compared to the negative speaking condition (*mean difference* = 1.028, *SE* = .327, p = .005); however, CWNS did not display a difference in SCL between the positive and negative speaking conditions.

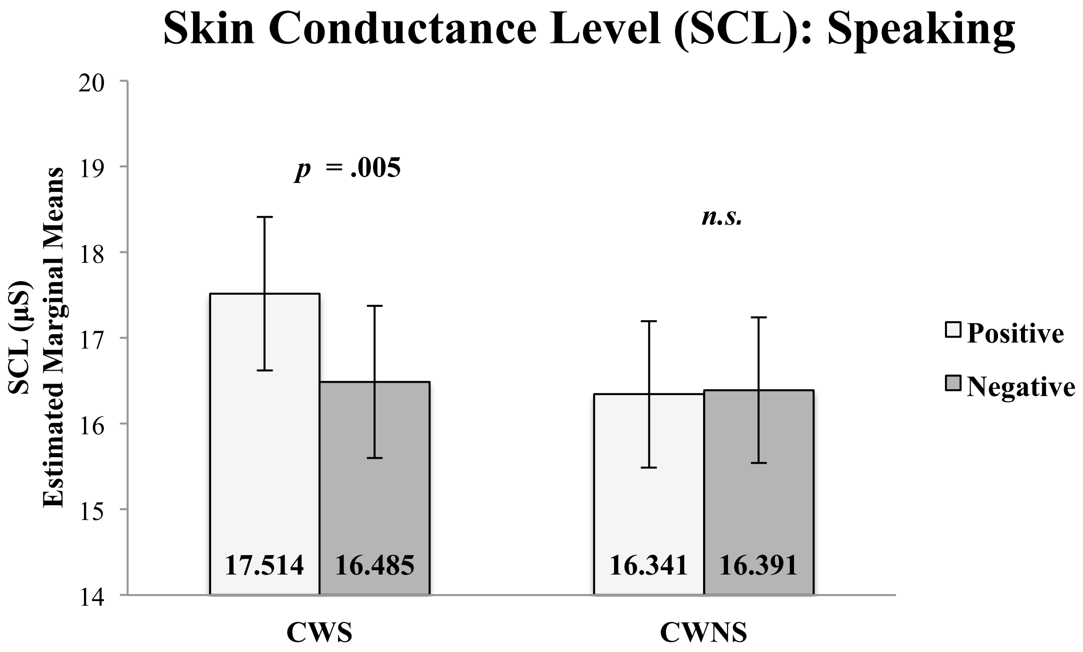

Figure 2. Skin conductance level (SCL): between-group interaction effect for preceding emotion conditions for preschool-age CWS (n = 20, 15 male) and CWNS (n = 21, 11 male) (± standard error). Values at the base of each column = SCL estimated marginal means for each talker group.

Respiratory sinus arrhythmia (RSA) was assessed during the narrative speaking conditions, each of which was preceded by a listening-viewing condition (pre-baseline, negative, positive). There was no significant between group difference for RSA or interaction of group and prior listening-viewing condition.

However, as shown in Figure 3[8], during speaking there was a significantly between-group difference in the relation between RSA and SCL, *F* (1, 149.03) = 7.410, *p* =.007, *d* = .45. Specifically, during speaking CWS exhibited a significant positive relation between RSA and SCL (est. $\beta = .034$, $p < .001$), whereas CWNS did not exhibit a significant relation between the two variables.

The significant between-group effects for SCL and the significant positive relation between RSA and SCL for CWS supported Hypothesis 3, however, the null findings for RSA between the groups for RSA during speaking did not support Hypothesis 3.

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[8] In Figure 3, following inferential assessment of the relation of RSA and SCL during the speaking conditions, CWS and CWNS were dichotomized into those who exhibited SCL below and above the median values.

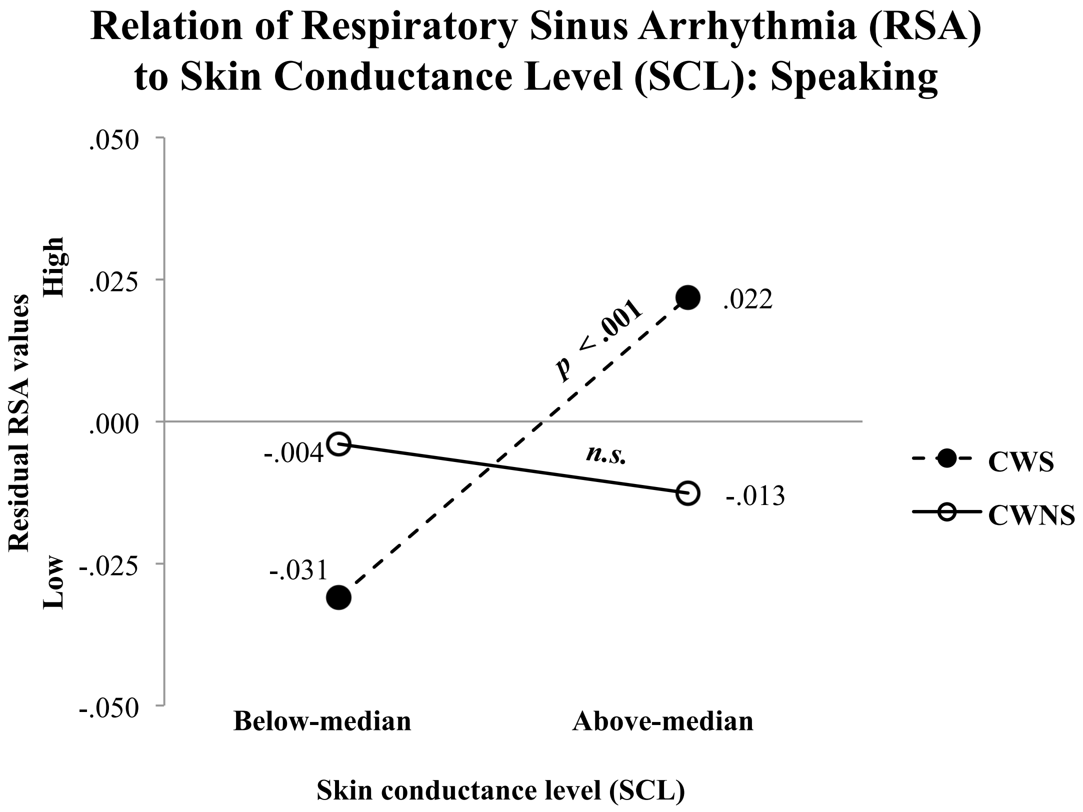

Figure 3. Residual respiratory sinus arrhythmia (RSA) values from the speaking linear mixed-effects model for preschool-age CWS (n = 20, 15 male) and CWNS (n = 21, 11 male) with low and high skin conductance level (SCL). Values beside each closed and open circle = residual RSA values for each talker group.

Physiological response to environment (i.e., change in experimental conditions re baseline) (Hypothesis 4)

Descriptive statistics pertaining to Hypothesis 4 are presented in Table 9. To test Hypothesis 4, that is, preschool-age CWS, compared to CWNS, exhibit *less* adaptive patterns of RSA-change and SCL-change to listening-viewing and speaking conditions (i.e., nonreciprocal or reciprocal sympathetic activation, see Table 1), inferential analyses were performed, with results depicted in Table 10.

Table 9

Descriptive statistics pertaining to Hypothesis 4 (i.e., ***response to environmental conditions,*** *listening-viewing vs. speaking) for respiratory sinus arrhythmia and skin conductance level change from baseline for preschool-age children who stutter (CWS, n=20, 15 male) and children who do not stutter (CWNS, n = 21, 11 male).*

	Respiratory Sinus Arrhythmia		**Skin Conductance Level**	
CWS	*M (SD)*	*Range*	*M (SD)*	*Range*
Listening-viewing	.03 (.74)	-2.55-2.22	.84 (6.56)	-11.81-22.69
Speaking	-.05 (.81)	-3.10-1.79	.48 (4.89)	-8.83-19.98
CWNS	*M (SD)*	*Range*	*M (SD)*	*Range*
Listening-viewing	-.07 (.87)	-2.90-3.44	-.97 (5.42)	-11.15-19.98
Speaking	.001 (.76)	-4.85-2.12	-.01 (4.20)	-8.67-18.30

Table 10

Inferential analyses (i.e., linear mixed-effects statistical models, Pinheiro & Bates, 2000) pertaining to Hypothesis 4 (i.e., ***response to environmental change****; listening-viewing vs. speaking) for respiratory sinus arrhythmia and skin conductance level for preschool-age children who stutter (CWS, n = 20, 15 male) and preschool-age children who do not stutter (CWNS, n = 21, 11 male).*

	Response to Environmental Change			
	Respiratory Sinus Arrhythmia		*Skin Conductance Level*	
Effect	*p* (sig.)	*d*	*p* (sig.)	*d*
Group	0.36	0.08	0.069	0.28
Group*task (listening-viewing versus speaking)	**0.015**	0.17	**<0.001**	0.3
Group*SCL	0.167*	0.09	-	-
Respiratory sinus arrthymia	-	-	0.73	0.02
Skin conductance level (SCL)	**0.04**	0.13	-	-
Task (listening-viewing versus speaking)	0.35	0.07	0.25	0.06
Gender	0.22	0.11	**0.017**	0.36
Body mass index (BMI)	0.054	0.17	**-**	-
Respiration	**0.006**	0.13	**-**	-
Age	**<0.001**	0.48	**0.033**	0.33

Notes. Only results applicable to the a priori hypothesis appear boxed, with significant findings **bolded**, and measures of effect size reported as Cohen's *d* (Cohen, 1992). *Indicates interaction effects that were initially included in statistical models, but removed when non-significant. "-" Indicates that the measure was not applicable to a particular analysis, and thus, not included in the statistical model.

Change in SCL from baseline (SCL-change) was measured during both the listening-viewing and speaking tasks. There was a non-significant between-group difference for SCL-change; however, there was a significant interaction of group by task (listening-viewing versus speaking), F (1, 1321.93) = 31.30, $p < .001$, $d = .30$. As shown in Figure 4, follow-up analyses indicated that CWS, when compared to CWNS, displayed greater SCL-change during listening-viewing (*mean difference* = 1.639, *SE* = .581, p = .005), but there was no significant difference between the groups during speaking.

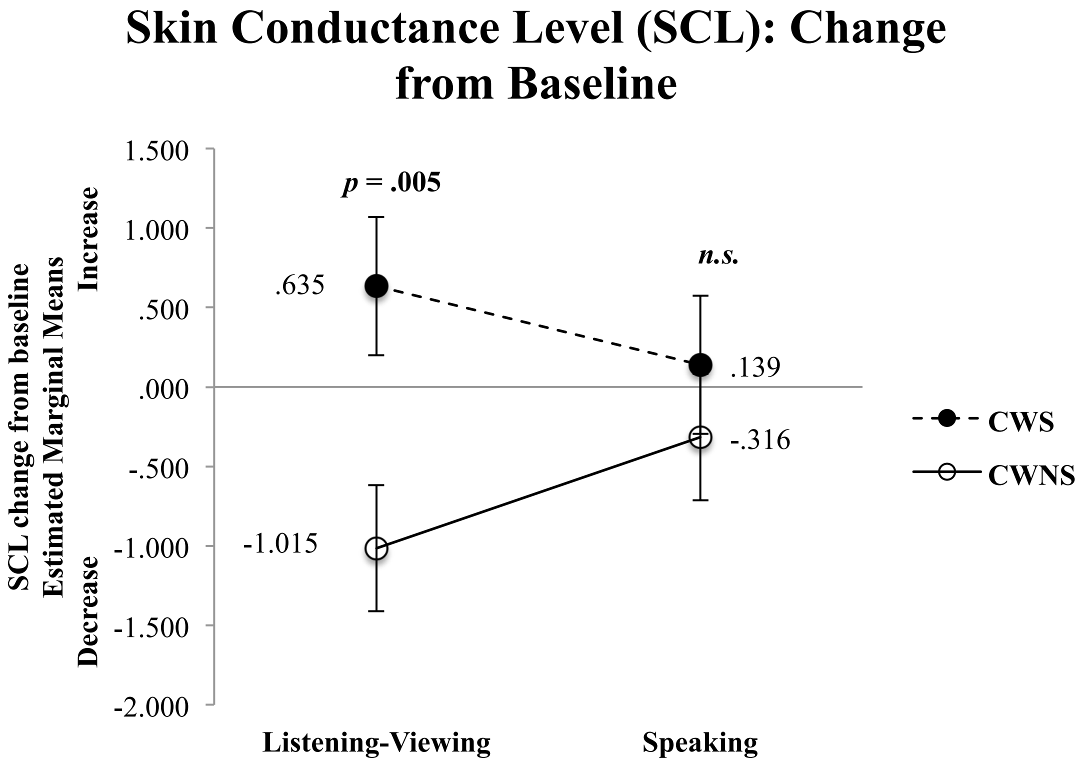

Figure 4. Skin conductance level change from baseline (SCL-change): between-group interaction effect for Listening-Viewing versus Speaking for preschool-age CWS (n = 20, 15 male) and CWNS (n = 21, 11 male) (± standard error). Values beside closed and open circles = SCL-change estimated marginal means for each talker group.

Change in RSA from baseline (RSA-change) was measured during listening-viewing and speaking tasks. There was no main effect of group for RSA-change. However, as shown in Figure 5, there was a significant interaction of group and task (listening-viewing versus speaking), *F* (1, 795.39) = 5.959, *p* = .015, *d* = .17. Further analysis indicated that CWS displayed lower RSA-change during speaking compared to listening-viewing (*mean difference* = -.103, *SE* = .044, *p* = .020), whereas CWNS displayed no difference between the listening-viewing and speaking tasks. In addition, this interaction indicates that CWS, compared to CWNS, exhibited significantly greater RSA-change during the listening condition (*mean difference* = .118, *SE* = .056, *p* = .037), whereas there was no difference between the groups during speaking.

There was a significant positive relation between SCL-change and RSA-change for both groups across speaking and listening-viewing conditions, *F* (1, 1045.89) = 4.262, *p* = .039, *d* = .13.

The significant between-group by task interaction effects for SCL-change and RSA-change supported Hypothesis 4, however, the lack of difference between the groups for the relation of SCL-change and RSA-change did not support Hypothesis 4.

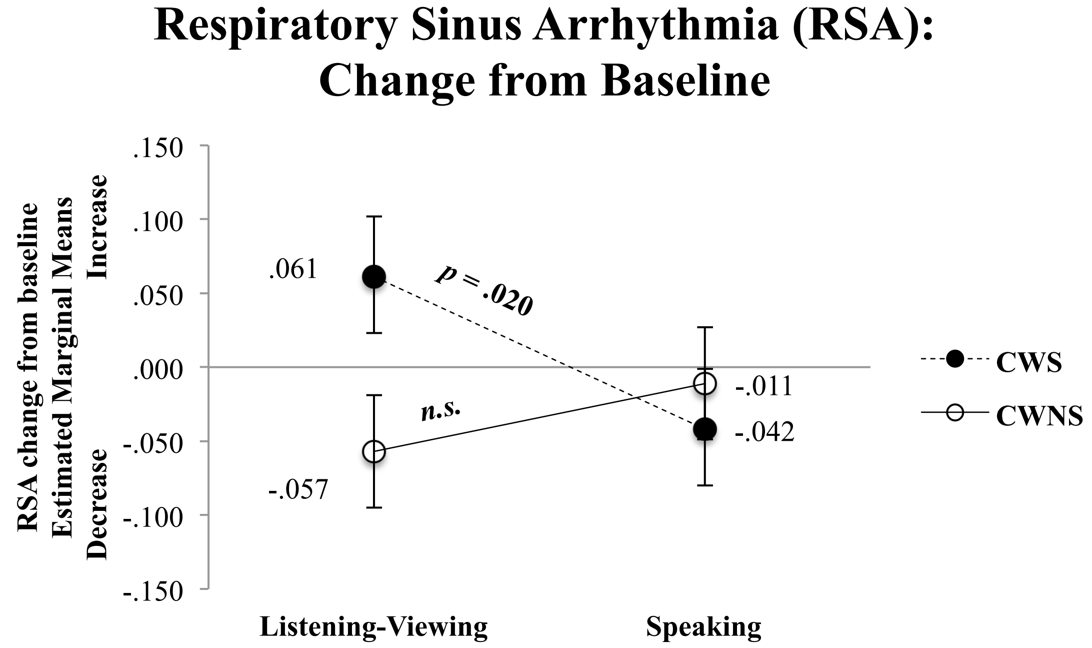

Figure 5. Respiratory sinus arrhythmia change from baseline (RSA-change): between-group interaction effect for Listening-Viewing versus Speaking for preschool-age CWS (n = 20, 15 male) and CWNS (n = 21, 11 male) (± standard error). Values beside closed and open circles = RSA-change estimated marginal means for each talker group.

Summary (of main findings)

There were main findings pertaining to each of the four a priori hypotheses. First, preschool-age CWS, compared to their CWNS peers, exhibited lower physiological *regulation* (i.e., RSA) at baseline. Second, CWS exhibited greater physiological *reactivity* (i.e., SCL) during the positive listening-viewing condition, whereas CWNS exhibited greater reactivity during the negative listening-viewing condition. Third, CWS displayed greater physiological reactivity during speaking (i.e., the narrative) following the positive, compared to the negative, condition, whereas CWNS did not show a differential response to the two conditions. In contrast, CWNS displayed no differential responses to the two emotion conditions. For CWS only, there was also a positive relation between physiological reactivity and regulation during speaking, suggesting that during speaking some preschool-age CWS react with decreases in RSA and SCL while others react with increases in RSA and SCL. Fourth, and finally, CWS, compared to CWNS, displayed greater increase in reactivity (i.e., SCL-change) during listening-viewing tasks as well as a significant decrease of regulation (i.e., RSA-change) during speaking compared to listening-viewing.

CHAPTER IV

DISCUSSION

The purpose of this study was to assess whether physiological reactivity and regulation differed between preschool-age CWS and CWNS during baseline, emotionally-arousing listening-viewing as well as speaking conditions. Previous studies of young CWS have assessed behavioral indices of emotional reactivity and regulation (e.g., Johnson et al., 2010; Schwenk et al., 2007; Walden et al., 2012) as well as physiological regulation (e.g., Jones et al., 2011)[9] during various tasks. However, to this writer's knowledge, very few studies (cf. Arnold et al., 2011) have concurrently measured of *physiological* reactivity and regulation in preschool-age children who stutter.

Physiological Reactivity and Regulation: Baseline

Present findings indicated that during baseline, preschool-age CWS did not differ from CWNS in terms of physiological reactivity, but they did exhibit significantly lower physiological regulation. This latter finding indicates that, in general, preschool-age CWS exhibit lower parasympathetic regulation of the heart. This finding is consistent with our initial predictions and Jones et al.'s (2011) finding that CWS display lower RSA across a variety of emotionally arousing listening-viewing and speaking conditions. Empirical evidence (e.g., Calkins, 1997; Calkins & Keane, 2004; Porges, et al., 1996) indicates that individuals with higher baseline RSA, compared to those with lower

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[9] Jones et al. (2011) represents a separate study of RSA in preschool-age CWS and CWNS using different participants than those employed in the present study.

baseline RSA, have a greater range within which cardiac activity may vary. This greater range of RSA is thought to allow for greater capacity for physiological responding to challenging situations. In addition, children exhibiting problems with behavioral regulation have lower baseline RSA (Porges, 1996), whereas children with higher baseline RSA display more positive affect (Calkins, 1997) and are at less risk for behavior problems (Calkins & Dedmon, 2000).

In general, the present finding that CWS exhibit lower physiological regulation at baseline is congruent with previous findings from caregiver reports that CWS, compared to CWNS, display stable proclivities toward greater reactivity (e.g., Eggers et al., 2010; Karrass et al., 2006) and poorer regulatory skills (e.g., Anderson et al., 2003; Eggers et al., 2010; Felsenfeld et al., 2010; Karrass et al., 2006). Eggers et al. (2010) suggested that temperamental proclivities toward increased reactivity and decreased regulation may contribute to stuttering in stress-related situations. If CWS do have a decreased potential for emotion regulation, then when dealing with challenging speaking situations and/or their instances of stuttering, they may be less prepared and able to regulate their emotions. This inability to regulate during difficult situations may contribute to stuttering, an observation consistent with findings based on behavioral indices of regulation (e.g., Arnold et al., 2011; Walden et al., 2012).

Physiological Reactivity and Regulation: Listening-Viewing

Current results did not support our initial prediction that CWS, compared to CWNS, would exhibit greater physiological reactivity during the emotionally-arousing listening-viewing conditions. However, a group by condition interaction indicated that

CWS exhibited greater SCL during the positive listening-viewing condition, whereas CWNS exhibited greater SCL during the negative listening-viewing condition. This pattern of physiological responding indicates that CWS exhibit increased autonomic arousal in positive-valenced listening-viewing situations, a pattern of responding that may occur during positive-valenced speaking situations as well. If this is true for CWS, then increased physiological arousal, like behavioral aspects of emotionality (Walden et al., 2012), may be associated with stuttering. Such a pattern of physiological responding and resultant influence on speech fluency would compliment Adams (1992) speculation that *positive* emotional arousal may contribute to or increase the likelihood of stuttering.

Physiological Reactivity and Regulation: Speaking

Similar to findings during listening-viewing, our initial prediction that CWS, compared to CWNS, would exhibit greater SCL in the narratives following the emotionally arousing conditions was not supported. However, preschool-age CWS displayed greater physiological *reactivity* during the narrative following the positive, compared to the negative, condition, whereas CWNS did not display differential responses to the two conditions. Building upon the above finding re listening-viewing (i.e., greater SCL for CWS during the positive condition), the current finding re speaking indicates that the increased arousal of CWS during the positive emotion condition carried into the following narrative condition. Similar to the above speculation re reactivity during a positive listening-viewing condition, it is possible that the speech-language planning and production system of CWS may be vulnerable to disruptions from *positive* emotionality (for similar speculation see Adams, 1992). Moreover, this finding seems to compliment Jones et al.'s (2011) finding that preschool-age CWS, when compared to CWNS, displayed lower RSA during a positive condition. When taken together, current findings and Jones et al.'s (2011) findings indicate that preschool-age CWS display higher physiological reactivity and lower regulation during positive conditions.

During speaking CWS displayed a significant positive *relation* between RSA and SCL, whereas CWNS displayed no such relation between the two variables. This finding partially supports our hypothesis that CWNS would exhibit reciprocal parasympathetic activity, and that CWS would exhibit a less adaptive pattern (e.g., non-reciprocal coactivation or coinhibition). Our hypothesis was based on the notion that increased parasympathetic influence supports social communication (Porges, 2007) and that reciprocal parasympathetic activation generally promotes relatively calmer physiological states (Berntson et al., 1991).

Thus, depending on experimental condition (i.e., listening-viewing vs. speaking), present findings indicate that preschool-age CWS either exhibit *coactivation* (both RSA and SCL are high) or *coinhibition* (both RSA and SCL are low). Patterns of coactivation may be associated with relatively dysregulated "fight-or-flight" responses to stressful or challenging situations (Porges, 1995, 2001). On the other hand, El-Sheik et al. (2009) speculate that physiological patterns of coinhibition may promote a more passive approach response to environmental conditions. In addition, El-Sheik et al. (2009) reported maternal, paternal and teacher reports of attention problems for children displaying patterns of coinhibition or coactivation, which seems to support empirical findings (Eggers et al., 2012; Felsenfeld et al., 2010) that CWS differ from CWNS in terms of attentional problems (cf. Johnson, Conture, & Walden, 2012). El-Sheik et al.'s

(2009) findings are consistent with others who have reported that reciprocal activation (Wetzel, Quigley, Morell, Eves, & Backs, 2006) is adaptive during cognitive challenge. Relative to stuttering, coactivation or coinhibition likely represent a less than fluency-facilitating physiological response, speculation consistent with Jones et al.'s (2011) finding that CWS display a decrease of RSA in response to speaking (i.e., social communication).

Physiological Response to Environmental Change

In response to the listening-viewing tasks, preschool-age CWS exhibited a greater increase in physiological *reactivity* (SCL-change) than CWNS, suggesting that they may be more reactive to changes in environmental stimuli. In general, these results provide psychophysiological support for behavioral findings that CWS are more emotionally reactive to emotional challenge (Johnson et al., 2010) as well as environmental change (Schwenk et al., 2007). It is possible that CWS' proclivity toward increased reactivity, coupled with their lower potential for emotion regulation, may contribute to less than well-regulated emotional processes during various challenging social/communicative situations. Regarding actual instances of stuttering, if preschool-age CWS are required to communicate in a positively- or negatively-valenced speaking situation, they may experience increases in arousal but lack the ability to sufficiently regulate that arousal. This seeming imbalance between reactivity and regulation may be less than facilitative to fluent initiation and/or maintenance of speech-language planning and production.

Furthermore, CWS exhibited significantly lower physiological *regulation* during speaking compared to listening-viewing. Based on Porges (2007) Polyvagal theory, it was hypothesized that a more adaptive pattern of responding would be increased parasympathetic activity (RSA-change) during social communication and decreased parasympathetic activity during emotional challenge. For CWS, however, the present writer found the opposite pattern of physiological regulation. This finding was taken to suggest that during speaking, CWS are engaging the "mobilization system" that supports behaviors of "fight" or "flight" rather than the "social communication system." It is possible that CWS engaged the "mobilization system" in response to the narrative task because it was perceived as a challenge in the social environment (Dickerson & Kemeny, 2004). Among many possibilities, CWS may display this pattern of responding because their: (a) speech-language planning and production systems are less than well developed to support fluent speech (for further theoretical speculation, see Conture & Walden, 2012; for further review of empirical findings see Ntourou, Conture, Lipsey, 2011), or (b) experiences with speaking (possibly related to stuttering) have resulted in their perception that speaking is difficult (for similar speculation, see Clark, Conture, Frankel, Walden, 2012). It should be noted that this finding is consistent with Jones et al.'s (2011) report that CWS displayed lower RSA-change during speaking compared to listening-viewing. However, present findings did not replicate Jones et al.'s (2011) finding that CWS, compared to CWNS, exhibited lower RSA-change during the speaking task.

Implications of Physiological Reactivity and Regulation for Children's Speech Fluency

As Conture et al. (2006) suggested, it is possible that both emotional reactivity and regulation may disrupt linguistic processing and thereby contribute to stuttering. Specifically, physiological reactivity and regulation may be associated or interact with processes that are thought to contribute to stuttering, such as (a) short term memory performance which is implicated in phonological processing (e.g., Anderson, Hall, &

Wagovich, 2006; Bajaj, 2007), (b) receptive and/or expressive language abilities (e.g., Ntourou, Conture, Lipsey, 2011) and (c) attentional processes (e.g., Eggers et al., 2012; Felsenfeld et al., 2010). Below we first discuss evidence that physiological reactivity and regulation are associated with such processes in young children. Following that, we will briefly discuss how these physiological processes may contribute to stuttering.

Physiological response and related cognitive and speech-language processes

Higher baseline RSA is predictive of better performance on tasks of working memory and cognitive efficiency in children aged six to thirteen years (Staton, El-Sheik, Buckhalt, 2008) as well as tasks of executive function in preschool-age children (e.g., number recall and children's stroop test; Marcovitch et al., 2010). Further, children with autism that have higher baseline RSA displayed better social behavior and receptive language abilities (Patriquin, Scarpa, Friedman, & Porges, 2011). In addition, Marcovitch et al. (2010) found that children who displayed moderate decrease in RSA during cognitive challenge performed better than those exhibiting too little or too much RSA decrease. Based on findings such as these, researchers (Calkins, 1997; Suess et al., 1994) have speculated that appropriate reactivity and regulation at baseline and in response to various situations facilitates the allocation of attentional and cognitive resources to the given task and improves performance.

Physiological response and speech fluency

Current findings indicate that CWS exhibit lower potential for emotion regulation (i.e., lower baseline RSA) coupled with less adaptive patterns of physiological reactivity and regulation during speaking. Based on the above discussion, it is possible that these maladaptive patterns of physiological responding may disrupt attentional, cognitive, and speech-language processes. As mentioned above, empirical evidence and theory suggest that these processes contribute to stuttering. Thus, one reasonably parsimonious account of the present findings is that CWS' pattern of physiological reactivity and regulation may interact with and disrupt a predisposed weakness in their speech-language planning and production and/or related processes (e.g., attention). Specifically, it is possible that the speech planning systems of CWS are less modularized (Bosshardt, 2006), providing less "protection" from speech disfluencies and stuttering when attentional, cognitive, and speech-language resources are disrupted by physiological reactivity and regulation. In general, this speculation is consistent with findings that stuttering is associated with emotional (Arnold et al., 2011; Walden et al., 2012) and cognitive stress (Caruso et al., 1994). Furthermore and similar to Eggers et al.'s (2010) speculation, a proclivity toward this pattern of responding may increase the likelihood that CWS would associate speaking situations with stress or challenge rather than a positive social communication opportunity, speculation consistent with that of the "experience" aspect of Conture et al.'s (2006) Communication-Emotional Model of Stuttering.

Limitations

The present study assessed physiological reactivity and regulation during a speaking task, but did not assess the association between physiological reactivity/regulation and instances of stuttering. Therefore, the possibility that patterns of physiological responding may be associated with stuttered speech is speculative rather than supported by empirical evidence.

Relatedly, between-group differences may be more reflective of speech, language, or voice than emotional processes. Specifically, the vagus nerve not only regulates cardiac but also oral communication activity, for example, activation of laryngeal muscles. Hence, given that stuttering is a disorder of speech, it is possible that differences in RSA may represent disruptions of speech rather than emotion. However, the precise interaction between vagal branches that impact cardiac versus communicative activity remain unclear.

In passing, it should be noted that there appears to be little empirical evidence regarding how the mode of stimuli (i.e., auditory, visual or combined) impacts physiological reactivity and regulation in preschool-age children. Arnold et al. (2011), using only auditory stimuli (i.e., auditory recordings of adults), reported that such stimuli affected preschoolers' behavioral indices of emotion regulation. In addition, Gilissen et al. (2007) reported physiological responses to listening-viewing stimuli in the preschool-age population. Thus, the relative influence of mode of emotionally challenging stimuli — (1) auditory alone, (2) visual alone or their (3) combination (as in the present study) — on preschoolers' physiological reactivity and regulation remains an open empirical question.

Berntson et al.'s (1991) *doctrine of autonomic space,* was specifically designed to describe sympathetic and parasympathetic activity on a singular target organ. The present study assessed parasympathetic influence on the heart (i.e., RSA) and electrodermal indices of sympathetic activity (i.e., SCL). Similar to the present study, El-Sheik et al. (2009) used the same measures (RSA and SCL) and found that SCL appeared to operate similar to preejection period (a measure of sympathetic activity on the heart).

Further research is necessary to better understand the relation between cardiac indices of parasympathetic activity and electrodermal indices of sympathetic activity.

In the present study, an effort was made to account for the possible influences of amount of talking on respiration and RSA. The amount of talking a participant produced during the speaking tasks was quantified by assessing the number of utterances that the participant produced during each narrative task. Further investigation is needed to determine how to best account for the amount of talking a participant produces and the influence of speaking (and other tasks) on RSA in preschool-age populations.

CHAPTER V

CONCLUSION

The present study explored differences between preschool-age CWS and CWNS in physiological reactivity (indexed by SCL and SCL-change) and regulation (indexed by RSA and RSA-change) during baseline, emotionally arousing listening-viewing and speaking tasks. Findings indicated that preschool-age CWS, compared to CWNS, displayed a lower potential for emotion regulation and for sustained attention. In addition, preschool-age CWS exhibited greater reactivity during the speaking task following the positive condition, compared to negative, whereas CWNS displayed no differences between the conditions. Lastly, and of particular interest, CWS exhibited a positive relation between SCL and RSA during speaking, whereas CWNS displayed no such relation between the variables.

These differences in physiological reactivity and regulation during speaking would seem less than facilitative of CWS' fluent speech-language planning and production, and may ultimately contribute to these children's stutterings. Perhaps, during speaking, CWS' relatively non-reciprocal parasympathetic and sympathetic activity may lead to less than adaptive concurrent emotional responding. By so doing, this may divert resources away from CWS' attentional, cognitive, and speech-language processes needed to fluently initiate and/or maintain communication, a possibility that must await further empirical study.

REFERENCES

Adams, M. R. (1992). Childhood stuttering under "positive" conditions. *American Journal of Speech-Language Pathology, 1*, 2.

Alm, P. A. (2004). Stuttering, emotions, and heart rate during anticipatory anxiety: a critical review. *Journal of Fluency Disorders, 29*(2), 123-133.

Alm, P. A., & Risberg, J. (2007). Stuttering in adults: the acoustic startle response, temperamental traits, and biological factors. *Journal of communication disorders, 40*(1), 1-41.

Anderson, J. D., Pellowski, M. W., Conture, E. G., & Kelly, E. M. (2003). Temperamental characteristics of young children who stutter. *Journal of Speech Language and Hearing Research, 46*(5), 1221-1233.

Anderson, J. D. Wagovich, S., & Hall, N. (2006). Nonword repetition skills in young children who do and do not stutter. *Journal of Fluency Disorders, 31 (3),* 177-199.

Andreassi, J L. (2000). *Psychophysiology: Human Behavior and Physiological Response* (4th ed.). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Arnold, H. S., Conture, E. G., Key, A. P., & Walden, T. (2011). Emotional reactivity, regulation and childhood stuttering: A behavioral and electrophysiological study. *Journal of communication disorders*, *44 (3),* 276-293.

Arnold, H. S. & MacPherson, M. K. (2012, March). Psychophysiological correlates of emotional processes in children who stutter. *Paper presented at the Third European Symposium on Fluency Disorders, Antwerp, Belgium.*

Baddeley, A. (2003). Working memory and language: An overview. *Journal of Communication Disorders, 36,* 189-208.

Bajaj, A. (2007). Working memory involvement in stuttering: Exploring evidence and research implications. *Journal of Fluency Disorders, 32 (3),* 218-238.

Baumgartner, J. M., & Brutten, G. J. (1983). Expectancy and heart rate as predictors of the speech performance of stutterers. *Journal of Speech and Hearing Research, 26*(3), 383-388.

Berntson, G. G., Cacioppo, J. T., Quigley, K. S. (1991). Autonomic determinism: The modes of autonomic control, the doctrine of autonomic space, and the laws of autonomic constraint. *Psychological Review, 98 (4),* 459-487.

Beauchaine, T. (2001). Vagal tone, development, and Gray's motivational theory: Toward an integrated model of autonomic nervous system functioning in psychopathology. *Development and Psychopathology, 13,* 183-214.

Blair, C. & Peters, R. (2003). Physiological and neurocognitive correlates of adaptive behavior in preschool among children in head start. *Developmental Neuropsychology, 24* (1), 479-497.

Blood, G. W., Blood, I. M., Bennett, S., Simpson, K. C., & Susman, E. J. (1994). Subjective anxiety measurements and cortisol responses in adults who stutter. *Journal of Speech and Hearing Research, 37*(4), 760-768.

Bloodstein, O., & Ratner, N. B. (2008). *A handbook on stuttering* (6th ed.). Clifton Park, NY: Thomson/Delmar Learning.

Bosshardt, H. G. (2006). Cognitive processing as a determinant of stuttering: Summary of a research programme. *Clinical Linguistics & Phonetics, 20(5),* 371-385.

Boucsein, W. (1992). *Electrodermal activity*. New York: Plenum Press.

Buhr, A. P., Conture, E. G., Frankel, C. B., & Walden, T. A. (2010). *Respiratory sinus arrhythmia and childhood stuttering*. Paper presented at the The American Speech-Language-Hearing Association annual conference, Philidelphia, PA.

Buhr, A. P., Conture, E. G., Kelly, E. M., & Jones, R. M. (2011). *Do preschoolers' stuttered repetitions originate as linguistic encoding errors?* Paper presented at the The American Speech-Language-Hearing Association annual conference, Philidelphia, PA.

Bush, A. (2006). *Effects of childhood stuttering on attention regulation in emotionally arousing situations.* Vanderbilt University, Nashville.

Calkins, S. D. (1997). Cardiac vagal tone indices of temperamental reactivity and behavioral regulation in young children. *Developmental Psychobiology, 31,* 125-135.

Calkins, S. D., & Dedmon, S. A. (2000). Physiological and behavioral regulation in two-year-old children with aggressive/destructive behavior problems. *Journal of Abnormal Psychology, 28,* 103-118.

Calkins, S. D., Graziano, P. A., & Keane, S. P. (2007). Cardiac vagal regulation differentiates among children at risk for behavior problems. *Biological psychology, 74*(2), 144-153.

Calkins, S. D., & Keane, S. P. (2004). Cardiac vagal regulation across the preschool period: stability, continuity, and implications for childhood adjustment. *Developmental psychobiology, 45*(3), 101-112.

Campbell, D. T., & Fiske, D. W. (1959). Convergent and discriminant validation by the multitrait-multimethod matrix. *Psychological bulletin, 56*(2), 25.

CardioBatch. (2007). Brain-Body Center, University of Illinois at Chicago.

CardioEdit. (2007). Brain-Body Center, University of Illinois at Chicago.

Caruso, A. J., Chodzko-Zajko, W. J., Bidinger, D. A., & Sommers, R. K. (1994). Adults who stutter: responses to cognitive stress. *Journal of Speech and Hearing Research, 37*(4), 746-754.

Clark, C. E., Conture, E. G., Frankel, C. B., & Walden, T. A. (2012). Communicative and psychological dimensions of the KiddyCAT. *Submitted for peer review.*

Cohen, J. (1992). A power primer. *Psychological Bulletin, 112,* 155-159.

Cole, P. M., Martin, S. E., & Dennis, T. A. (2004). Emotion regulation as a scientific construct: Methodological challenges and directions for child development research. *Child Development, 75*(2), 317-333.

Cole, P. M., Zahn-Waxler, C., Fox, N. A., Usher, B. A., & Welsh, J. D. (1996). Individual differences in emotion regulation and behavior problems in preschool children. *Journal of Abnormal Child Psychology, 105*, 518-529.

Conture, E. G., & Walden, T. A. (2012). Dual Diathesis-Stressor Model of Stuttering. In L. Beliakova & Y. Filatova (Eds.), *Theoretical Issues of Fluency Disorders* (pp. 94-127). Moscow: Vlados.

Conture, E. G., Walden, T. A., Arnold, H. S., Graham, C. G., Hartfield, K. N., & Karrass, J. (2006). A communication-emotional model of stuttering. In A. Bernstein Ratner, & J. Tetnowski (Eds.), *Current issues in stuttering research and practice* (pp. 17–46). Mahwah, NJ: Lawrence Erlbaum Associates, Publishers.

Denver, J. W., Reed, S. F., & Porges, S. W. (2007). Methodological issues in the quantification of respiratory sinus arrhythmia. *Biological Psychology, 74,* 286-294.

Doussard-Roosevelt, J. A., Montgomery, L. A., & Porges, S. W. (2003). Short-term stability of physiological measures in kindergarten children: respiratory sinus arrhythmia, heart period, and cortisol. *Developmental psychobiology, 43*(3), 230-242.

Dunn, L., & Dunn, L. (1997). *Peabody picture vocabulary test-III (PPVT-III) (3rd ed.).* Circle Pines, MN: American Guidance Service, Inc.

Eggers, K., De Nil, L. F., & van Den Bergh, B. R. H. (2009). Factorial temperament structure of stuttering, voice disordered, and normal speaking children. *Journal of Speech, Language and Hearing Research, 52,* 1610-1622.

Eggers, K., De Nil, L. F., & Van den Bergh, B. R. (2010). Temperament dimensions in stuttering and typically developing children. *Journal of Fluency Disorders, 35*(4), 355-372.

Eggers, K., De Nil, L. F., & Van den Bergh, B. R. (2012). The efficiency of attentional networks in children who stutter. *Journal of Speech, Language, and Hearing Research*, 55 (3), 946-959.

El-Sheikh, M., Kouros, C. D., Erath, S., Cummings, E. M., Keller, P., & Staton, L. (2009). Marital Conflict and Children's Externalizing Behavior: Interactions between Parasympathetic and Sympathetic Nervous System Activity. *Monographs of the Society for Research in Child Development, 74*(1), 1-+.

Ellis, J. B., Finan, D. S., & Ramig, P. R. (2008). The influence of stuttering severity on acoustic startle responses. *Journal of speech, language, and hearing research : JSLHR, 51*(4), 836-850.

Embrechts, M., Ebben, H., Franke, P., & van de Poel, C. (2000). Temperament: A comparison between children who stutter and children who do not stutter. In H.-G. Bosshardt, J. Yaruss & H. Peters (Eds.), *Proceedings of the Third World Congress on Fluency Disorders: Theory, research, treatment and self-help*, (pp. 557-562). University of Mijmegen, The Netherlands: Nimegen Press.

Fabes, R. A., Eisenberg, N., & Eisenbud, L. (1993). Behavioral and physiological correlates of children's reactions to others in distress. *Developmental Psychology, 29,* 655-663.

Fabes, R. A., Eisenberg, N., Karbon, M., Bernzweig, J., Speer, A. L., & Carlo, G. (1994). Socialization of children's vicarious emotional responding and prosocial behavior: Relations with Mothers' perceptions of children's emotional reactivity. *Developmental Psychology, 30 (1),* 44-55.

Felsenfeld, S., van Beijsterveldt, C. E. M., & Boomsma, D. I. (2010). Attentional Regulation in Young Twins With Probable Stuttering, High Nonfluency, and Typical Fluency. *Journal of Speech Language and Hearing Research, 53*(5), 1147-1166.

Fowles, D. C., Kochanska, G., & Murray, K. (2000). Electrodermal activity and temperament in preschool children. *Psychophysiology, 37*, 777-787.

Gentzler, A. L., Santucci, A. K., Kovacs, M., Fox, N. A. (2009). Respiratory sinus arrhythmia reactivity predicts emotion regulation and depressive symptoms in at-risk and control children. *Biological Psychology, 82,* 156-163.

Gilissen, R., Bakermans-Kranenburg, M. J., van Ijzendoorn, M. H., & Linting, M. (2008). Electrodermal reactivity during the Trier Social Stress Test for children: interaction between the serotonin transporter polymorphism and children's attachment representation. *Developmental psychobiology, 50*(6), 615-625.

Gilissen, R., Koolstra, C. M., van Ijzendoorn, M. H., Bakermans-Kranenburg, M. J., & van der Veer, R. (2007). Physiological reactions of preschoolers to fear-inducing film clips: effects of temperamental fearfulness and quality of the parent-child relationship. *Developmental psychobiology, 49*(2), 187-195.

Goldman, R., & Fristoe, M. (2000). *Goldman Fristoe 2 test of articulation* (2nd ed.). Circle Pines, MN (Publishers' Bldg., Circle Pines 55014-1796): American Guidance Service.

Golub, A. J. (1953). The heart rates of stutterers and nonstutterers in relation to frequency of stuttering during a series of oral readings. *Speech Monographs, 20*, 146-147.

Graziano, P. A., Keane, S. P., & Calkins, S. D. (2007). Cardiac vagal regulation and early peer status. *Child Development, 78*(1), 264-278.

Guitar, B. (2003). Acoustic startle responses and temperament in individuals who stutter. *Journal of Speech Language and Hearing Research, 46*(1), 233-240.

Hollingshead, A. (1975). *Four factor index of social status*. Yale University. New Haven, CT.

Hresko, W. P., Reid, D. K., Hammill, D. D., & Pro-Ed (Firm). (1999). *TELD-3 : test of early language development : examiner's manual* (3rd ed.). Austin, Texas: Pro-ed.

Jennings, J. R., Tahmoush, A. J., & Redmond, D. P. (1980). Non-invasive measurement of peripheral vascular activity. In I. Martin & P. H. Venables (Eds.), *Techniques in psychophysiology* (pp. 69-137). London: John Wiley & Sons.

Johnson, K. N., Conture, E. G., & Walden, T. A. (2012). Efficacy of attention regulation in preschool-age children who stutter: A preliminary investigation. *Journal of Communication Disorders, 45,* 263-278.

Johnson, K. N., Walden, T. A., Conture, E. G., & Karrass, J. (2010). Spontaneous Regulation of Emotions in Preschool Children Who Stutter: Preliminary Findings. *Journal of Speech Language and Hearing Research, 53*(6), 1478-1495.

Jones, R. M., Buhr, A. P., Frankel, C. B., Conture, E. G., & Walden, T. A. (2011). *Respiratory sinus arrhythmia prior and during narratives of preschool-age children who stutter*. Paper presented at the The American Speech-Language-Hearing Association annual conference, San Diego, CA.

Jones, R. M., Conture, E. G., Frankel, C. B., & Walden, T. A. (2010). *Emotional reactivity and regulation initiated prior to and during (dis)fluent utterances of preschool-age children who stutter*. Paper presented at The American Speech-Language-Hearing Association annual conference, Philidelphia, PA.

Jones, R. M., Fox, R. A., & Jacewicz (in press). The effects of concurrent cognitive load on phonological processing in adults who stutter. *Journal of Speech, Language, and Hearing Research.*

Karrass, J., Walden, T. A., Conture, E. G., Graham, C. G., Arnold, H. S., Hartfield, K. N., & Schwenk, K. A. (2006). Relation of emotional reactivity and regulation to childhood stuttering. *Journal of communication disorders, 39*(6), 402-423.

Klimenko, V. M., Vovk, O. N., Yakovlev, N. M., Burmistrov, A. S., Litke, A. S. (2007). Respiratory sinus arrhythmia as an objective criterion for studying and optimizing speech breathing parameters. *Human Physiology, 33 (4),* 441-449.

Kraaimaat, F. L., Janssen, P., & Brutten, G. J. (1988). The relationship between stutterers' cognitive and autonomic anxiety and therapy outcome. *Journal of Fluency Disorders, 13*, 107-113.

Lewis, G. (2010). RespFreqFromRSA [Computer software]. Brain-Body Center, University of Illinois at Chicago.

Lewis, G., Furman, S., McCool, M., & Porges, S. (2012). Statistical strategies to quantify respiratory sinus arrhythmia: Are commonly used metrics equivalent? *Biological Psychology, 89,* 349-364.

Littell, R. C., G. A. Milliken, et al. (2006). SAS System for Mixed Models, Second Edition. Cary, N.C., SAS Institute.

Liu, C., Conn, K., Sarkar, N., & Stone, W. (2008). Physiology-based affect recognition for computer-assisted intervention of children with Autism Spectrum Disorder. *International Journal of Human-Computer Studies, 66*(9), 662-677.

Marcovitch, S., Leigh, J., Calkins, S. D., Leerks, E. M., O'Brien, M., & Blankson, A. N. (2010). Moderate vagal withdrawl in 3.5-year-old children is associated with optimal performance on executive function tasks. *Developmental Psychobiology,* 603-608.

McEwen, B. S., Seeman, T. (1999). Protective and damaging effects of mediators of stress: Elaborating and testing the concepts of allostasis load. *Annals of the New York Academy of Sciences, 896,* 30-47.

Miller, J., & Iglesias, A. (2008). Systematic Analysis of Language Transcipts (SALT) (Version Research Version 2008 [Computer Software]): SALT Software, LLC.

Monroe, S. M., & Simons, A. D. (1991). Diathesis-stress theories in the context of life stress research: implications for the depressive disorders. *Psychological bulletin, 110*(3), 406-425.

Ntourou, K., Conture, E. G., & Lipsey, M. W. (2011). Language abilities of children who stutter: A meta-analytical review. *American Journal of Speech-Language Pathology, 20*, 163-179.

Ntourou, K., Conture, E. G., & Walden, T. (2011). *Emotional reactivity and regulation in preschool-age children who stutter*. Paper presented at the American Speech-Language-Hearing Association annual conference, San Diego, CA.

Ortega, A. Y., & Ambrose, N. (in press). Developing physiologic stress profiles for school-age children who stutter. *Journal of Fluency Disorders*.

Patel, C. H. (1973). Yoga and bio-feedback in the management of hypertension. *Lancet, 1,* 1053-1055.

Patriquin, M. A., Scarpa, A., Friedman, B. H., & Porges, S. W. (2011). Respiratory sinus arrhythmia: A marker for positive social functioning and receptive language skills in children with autism spectrum disorders. *Developmental Psychobiology,* 1-12.

Peters, H. F. M., & Hulstijn, W. (1984). Stuttering and anxiety: The difference between stutterers and nonstutterers in verbal apprehension and physiologic arousal during the anticipation of speech and non-speech tasks. *Journal of Fluency Disorders, 9*(1), 67-84.

Pinheiro, J. C., & Bates, D. M. (2000). Mixed-effects models in S and S-Plus. New York, NY: Springer.

Porges, S. W. (1985). Washington DC Patent No. 4,510,944. U. S. P. Office.

Porges, S. W. (1995). Orienting in a defensive world: Mammalian modifications of our evolutionary heritage. A polyvagal theory. *Psychophysiology, 32,* 301-318.

Porges, S. W. (1997). Emotion: An evolutionary by-product of the neural regulation of the autonomic nervous system. *Annals of the New York Academy of Sciences, 807 (1),* 62-77.

Porges, S. W. (2001). The polyvagal theory: phylogenetic substrates of a social nervous system. *International journal of psychophysiology : Official journal of the International Organization of Psychophysiology, 42*(2), 123-146.

Porges, S. W. (2007). The polyvagal perspective. *Biological Psychology, 74*(2), 116-143.

Porges, S. W., & Bohrer, R. E. (1990). Analyses of periodic processes in psychophysiological research. In J. T. Cacioppo & L. G. Tassinary (Eds.), *Principles of Psychophyiology: Physical, Social, and Inferential Elements* (pp. 708-753). New York: Cambridge University Press.

Porges, S. W., Doussard-Roosevelt, J. A., Portales, A. L., & Greenspan, S. I. (1996). Infant regulation of the vagal "brake" predicts child behavior problems: a psychobiological model of social behavior. *Developmental psychobiology, 29*(8), 697-712.

Postma, A. & Kolk, H.H.J. (1993). The covert repair hypothesis: Prearticulatory repair processes in normal and stuttered disfluencies. *Journal of Speech and Hearing Research, 36,* 472-487.

Rosenthal, R., & DiMatteo, M. R. (2001). Meta analysis: Recent developments in quantitive methods for literature reviews. *Annual Review of Psychology, 52,* 59-82.

Rothbart, M. K., Ahadi, S. A., & Evans, D. E. (2000). Temperament and personality: Origins and outcomes. *Journal of Personality and Social Psychology, 78*(1), 122-135.

Schwenk, K. A., Conture, E. G., & Walden, T. A. (2007). Reaction to background stimulation of preschool children who do and do not stutter. *Journal of communication disorders, 40*(2), 129-141.

Staton, L., El-Sheik, M., & Buckhalt, J. A. (2008). Respiratory sinus arrhythmia and cognitive functioning in children. *Developmental Psychobiology,* 249-258.

Suess, P. E., Porges, S. W., & Plude, D. S. (1994). Cardiac vagal tone and sustained attention in school-age children. *Psychophysiology, 31,* 17-22.

Travis, L. E., Tuttle, W. W., & Cowan, D. W. (1936). A study of the heart rate during stuttering. *Journal of Speech Disorders, 1*, 21-26.

Treon, M. (2010). Revised stuttering and related TPNB-LPPD threshold syndrome hypothesis in light of recent research. *Psychology and Education, Monograph 47 (No. 3 & 4).*

van der Merwe, B., Robb, M., Lewis, J. G., & Ormond, T. (2011). Anxiety measures and salivary cortisol responses in preschool children who stutter. *Contemporary Issues in Communication Sciences and Disorders, 38*, 1-10.

Venables, P. H., & Christie, M. J. (1980). Electrodermal activity. In I. Martin & P. H. Venables (Eds.), *Psychophysiological techniques* (pp. 4-67). London: John Wiley & Sons.

Walden, T. A., Frankel, C. B., Buhr, A. P., Johnson, K. N., Conture, E. G., & Karrass, J. M. (2012). Dual Diathesis-Stressor Model of Emotional and Linguistic Contributions to Developmental Stuttering. *Journal of Abnormal Child Psychology, 40,* 633-644.

Walker, S. T., & Walker, J. M. (1973). Differences in heart-rate variability between stutterers and nonstutterers following arousal. *Perceptual and motor skills, 36*(3), 926.

Watson, L. R., Baranek, G. T., Roberts, J. E., David, F. J., & Perryman, T. Y. (2010). Behavioral and physiologcal responses to child-directed speech as predictors of communication outcomes in children with autism spectrum disorders. *Journal of Speech, Language, and Hearing Research, 53,* 1052-1064.

Weber, C. M., & Smith, A. (1990). Autonomic Correlates of Stuttering and Speech Assessed in a Range of Experimental Tasks. *Journal of Speech and Hearing Research, 33*(4), 690-706.

Weber, E. J., Ven Der Molen, M. W., & Molenaar, P. C. M. (1994). Heart rate and sustained attention during childhood: Age changes in anticipatory heart rate, primary bradycardia, and respiratory sinus arrhythmia. *Psychophysiology, 31,* 164-174.

Wetzel, J. M., Quigley, K. S., Morell, J., Eves, E., Backs, R.W. (2006). Cardiovascular measures of attention to illusory and nonillusory visual stimuli. *Journal of Psychophysiology, 20 (4),* 276-285.

Wilcoxson, J. (2012). *Receptive vocabulary of preschool-age children who stutter.* Paper to be presented at the The American Speech-Language-Hearing Association annual conference, Atlanta, GA.

Williams, K. (1997). *Expressive Vocabulary Test (EVT)*. Circle Pines, MN: American Guidance Service, Inc.

Zentner, M., & Bates, J. E. (2008). Child temperament: An integrative review of concepts, research programs, and measures. *European Journal of Developmental Science, 2*(1/2), 31.

APPENDIX A

Table A

Psychophysiological measures and stuttering. After Buhr, A., Frankel, C., Walden, T., Conture, E., Porges, S. (2010). Respiratory sinus arrhythmia and childhood stuttering. Unpublished manuscript.

Physiological Measures

Skin Conductance

Study	**Year**	**Participants**	**Tasks**	**Findings**
Adams & Moore	1972	12 AWS	Reading aloud with masking noise (90 dB)	Stuttering frequency reduced in masking condition Palmar sweat levels did not change across masking/no masking conditions Stuttering frequency not related to palmar sweat levels
Brutten	1963	33 AWS 33 AWNS	Adaptation with oral and silent passages of read text	Stuttering rate and palmar sweat decreased from 1st to 3rd oral readings for AWS Stuttering rate and palmar sweat did not decrease over silent reading expectancy
Dietrich & Roaman	2001	20 AWS	Questionnaire 20 hypothetical speech situations; SC in 4 actual speech situations	Hypothetical situations designed to be anxiety eliciting reported so by participants Four speaking tasks designed to differ in anxiety confirmed in participants However no correlation between expected and actual measures of SC
Gray & Brutten	1965	21 AWS	4 conditions adaptation exp. with rest & new text to read	No increase in palmar sweat antecedent to stuttering recovery No decrease in palmar sweat antecedent to stuttering adaptation
Gray & Karmen	1967	33 AWS 33 AWNS	Adaptation experiment	Disfluency & palmar sweat decreased for both groups over five readings of text No sig. difference between groups in level of palmar sweat across five readings
Reed & Lingwall	1976	10 AWS	Monologues with 95 dB noise punishment after stuttering	Stuttering decreased during punishment and increased during extinction Skin response did not change, not related to punishment

Table A, continued

Reed & Lingwall	1980	10 AWS	Monologues with female face with laughter after stuttering	Stuttering decreased with punishment of female face and laughter Skin response did not change, not related to punishment
Heart Rate				
Baumgartner & Brutten	1988	3 AWS	Expectancy to stutter on 80 words and subsequent reading	HR & HRV not related to expectancy or stuttering for two participants HR predictive of stuttering and HR & HRV predictive of expectancy for one participant
Golub	1953	26 AWS 28 AWNS	Baseline and adaptation on oral reading task	HR did not differ between groups; HR increased prior to and during speech HR lower during passages with stuttering than fluent
Klimenko, Vovk, Yakovlev, Burmistrov, & Litke	2007	AWS AWNS n unspecified	Baseline and reading a text (prose) aloud	Respiratory sinus arrhythmia (RSA) was used as physiological external feedback for changing speech breathing, speech and speech behavior. When RSA decreased, and HR and respiration increased, AWS displayed increased stuttered speech.
Palmer & Gillette	1938	24 AWS 28 AWNS	Resting in silent booth	Male AWS faster HR than AWNS basal conditions HR decreases as individuals get older
Palmer & Gillette	1939	21 AWS 24 AWNS	Resting in silent booth	AWS show less HRV than controls in baseline condition HR slows down more during expiration for AWNS compared to AWNS HR speeds up more during inspiration in AWNS compared to AWS
Ritzman	1943	29 AWS 29 AWNS	Resting in silent booth	More precise methodology including time of day and skin surface Basal HR no different AWS and AWNS; AWS less RSA during respiration but not sig. RSA and HR sig. negative correlations for both AWS and AWNS BP not different between the AWS and AWNS suggested emotional aspects of stuttering reduction reflected in vagal tone
Travis, Tuttle, & Cowan	1936	15 AWS 16 AWNS	Silence and oral readings	Faster HR and standard deviations for AWS both before (silence) and during speech HR faster and standard deviation during speech than during silence for both groups No differences in change in HR during respiratory cycles

Table A, continued

Walker & Walker	1973	10 AWS 10 AWNS	Auditory tone burst (65 & 105 dB) for two-second duration	HR did not differ between male AWS & AWNS at baseline
Multiple Measures				
Berlinsky	1955	14 AWS 14 AWNS	Tracking task of moving spot under stress of electric shock	AWS lower HR than AWNS in speech/non-speech tasks AWS higher GSR than AWNS on non-speech task AWS/PWNS did not differ in level of chronic anxiety
Caruso, Chodzko- Zajko, Bidinger, & Sommers	1994	9 AWS 9 AWNS	Condition 1: color reading; 2: read color plus speed; 3 Stroop task plus speed	BP not different between groups; mean BP increased on conditions 2 & 3 HR not different between groups on condition 1; only AWNS increased conditions 2 & 3 Both groups increased word length & vowel duration; AWS sig. more conditions 2 & 3 AWS slower latency & rate conditions 2 & 3; AWS more disfluencies conditions 2 & 3
Fletcher	1914	9 AWS	Speaking & reading	Volumetric change (BP) observed when called to speak or read correlated with severity HR higher prior to speech than normal; HR greater during speech than prior to GSR measures higher during speech than before & after correlated with severity
Kraaimaat, Janssen, & Brutten	1988	33 AWS	Silent and oral reading	Higher pre treatment SCL, higher SLDs post treatment No decrease post treat/HR pre not related to SLD post Decrease anxiety post treat/SRA pre not related to SLD post
Myers	1978	8 PWS	Answer 40 questions and repeat 40 multisyllabic words	Respiration, SCL, SCR, EMG, pulse volume prior to SLD correlated to severity No consistent pattern of physio variables to severity across participants
Peters & Hulstijn	1984	24 AWS 24 AWNS	Read text silently/aloud; conversation; mirror writing	More anxiety reported for AWS than AWNS for speech tasks Both groups show greater SCL, SCR, PV, HR before/during speech tasks No difference between AWS and AWNS in anticipation of speech tasks AWNS higher HR anticipation than AWNS of spontaneous speech

Table A, continued

Weber & Smith	1990	19 AWS 19 AWNS	Jaw movement; Valsava maneuver; read passage 10 times; answer 15 questions	Speaking associated with high SCL, SCR, HR, PV during speech for AWS/AWNS No group differences in autonomic arousal during baseline or speech tasks Autonomic arousal during disfluent trials of AWS no different than AWNS fluent trials Autonomic arousal correlated with disfluent behavior prior to disfluent utterances
Zhang, Kalinowski Saltuklaroglu, & Hudock	2010	15 AWS 21 AWNS	Skin conductance and Heart rate responses to stuttered speech	Both groups showed significant skin conductance response increase and heart rate decrease in response to observed stuttered speech
Other Measures				
Alm & Risberg	2007	32 AWS 28 AWNS	Conversational speech, anxiety questionnaires, and EMG response to acoustic pulses	AWS and AWNS no different in magnitude of acoustic startle response Magnitude of acoustic startle response not correlated with trait anxiety/stuttering severity AWS slightly higher trait anxiety than AWNS
Blood, Blood, Bennet, Simpson, & Sussman	1994	11 AWS 11 AWNS	Three conversational speech samples: baseline, low, and high stress	AWS higher cortisol response than AWNS in high stress condition AWS higher cortisol response in high stress vs. baseline and low stress conditions No significant group differences in state, trait, or communicative anxiety scores No significant correlations among cortisol, stuttering severity, and subjective anxiety
Dabul & Perkins	1973	16 AWS	Before and after electroshock with high & low stuttering	Greater decrease in BP after high-stuttering than low-stuttering condition
Guitar	2003	14 AWS 14 AWNS	Temperament scales and EMG response to acoustic bursts	AWS greater than ANWS on initial and 10 average startle responses No significant correlation between startle magnitude and stutter severity Temperament questionnaire no different between groups

Table A, continued

Horovitz, Johnson, Pearlman, Schaffer, & Hedin	1978	9 AWS 9 AWNS	Palmar sweat response while imagining stressful situation, & stapedial response to noise	AWS and AWNS no different in stapedial reflex with and without anxiety present Only AWS showed higher stapedial with anxiety versus without anxiety AWS and AWNS no difference in palmar sweat
Ickes & Pierce	1973	10 AWS 10 AWNS	Word reading	BP on fluent utterances no different from stuttered utterances for both groups Only disfluent utterances for AWS were different from PWNS Stutterers greater non-stutterers prior, before, during speech

APPENDIX B

Table B1

***Respiratory sinus arrhythmia (RSA)**, for each of seven conditions (i.e., Pre-baseline, Narrative #1, Negative, Narrative #2, Positive, Narrative #3, Post-baseline) for each preschool-age child who stutters (CWS, n = 20, 15 male). Age is expressed in months, and RSA is expressed in ln (ms)^2 (i.e., natural log of RSA estimate, for further details, see Lewis et al., 2012).*

			Respiratory sinus arrhythmia: Children who stutter (CWS)						
Participant	Age	Gender	Pre-baseline	Narrative #1	Negative	Narrative #2	Positive	Narrative #3	Post-baseline
1	37	Female	7.16	6.10	7.13	5.96	7.45	6.22	5.74
2	48	Male	5.14	5.52	5.51	5.40	5.56	4.81	5.08
3	43	Male	4.13	3.84	4.23	3.63	3.32	3.57	4.34
4	40	Male	8.45	8.28	9.01	7.37	8.63	7.82	8.56
5	42	Female	6.21	5.79	6.11	5.51	6.51	5.69	5.96
6	56	Male	8.08	7.59	7.84	7.30	8.11	7.19	8.02
7	36	Male	5.35	4.52	6.40	4.26	6.53	4.52	5.42
8	43	Male	4.94	4.57	4.39	4.29	3.73	4.39	4.63
9	44	Female	5.58	5.65	4.98	5.09	4.75	4.96	4.98
10	62	Male	7.13	6.14	7.17	5.82	7.59	5.87	7.12
11	50	Female	4.93	4.28	5.38	4.28	5.36	4.76	4.81
12	61	Male	6.49	6.35	6.67	5.75	6.62	5.19	6.67
13	38	Male	6.40	5.98	6.37	6.02	6.41	6.32	5.95
14	68	Male	7.54	7.15	7.99	7.03	8.17	6.93	8.06
15	71	Female	4.89	4.64	4.74	4.96	4.95	4.90	5.32
16	54	Male	5.32	4.41	6.61	4.33	6.30	3.95	5.82
17	36	Male	5.87	3.87	4.38	3.08	4.59	3.33	4.96
18	51	Male	5.01	5.00	5.50	4.71	5.04	4.66	4.89
19	54	Male	7.36	6.68	7.01	6.23	7.05	6.13	6.42
20	37	Male	4.35	4.17	3.85	3.08	4.14	3.63	3.54
Mean	48.55		6.02	5.53	6.06	5.21	6.04	5.24	5.81

Table B2

***Respiratory sinus arrhythmia (RSA)**, for each of seven conditions (i.e., Pre-baseline, Narrative #1, Negative, Narrative #2, Positive, Narrative #3, Post-baseline) for each preschool-age child who does not stutter (CWNS, n = 21, 11 male). Age is expressed in months, and RSA is expressed in ln (ms)^2 (i.e., natural log of RSA estimate, for further details, see Lewis et al., 2012).*

			Respiratory sinus arrhythmia: Children who do not stutter (CWNS)						
Participant	Age	Gender	Pre-baseline	Narrative #1	Negative	Narrative #2	Positive	Narrative #3	Post-baseline
1	70	Male	6.28	6.16	5.46	5.86	6.49	5.44	5.80
2	47	Male	6.97	6.32	7.05	5.94	7.63	5.74	6.59
3	42	Female	7.37	6.62	5.39	5.76	6.29	5.59	6.18
4	41	Female	6.24	6.01	6.10	6.23	6.21	6.58	6.26
5	43	Female	5.45	5.11	6.46	5.02	5.44	5.60	6.00
6	43	Female	7.81	7.37	7.84	7.09	7.82	6.68	7.72
7	46	Female	8.63	7.62	8.30	7.18	8.13	7.39	7.93
8	37	Male	6.25	5.96	5.98	5.42	6.02	5.64	6.45
9	61	Male	7.45	6.74	6.65	6.14	7.65	6.78	7.44
10	42	Female	7.12	6.00	6.16	5.55	6.34	5.96	6.92
11	48	Male	7.13	6.57	7.13	5.89	7.13	6.11	7.26
12	47	Female	5.86	5.35	5.99	5.16	6.12	5.08	5.12
13	59	Male	5.94	5.71	7.12	5.55	8.18	6.49	7.14
14	38	Female	6.97	6.37	5.36	6.34	6.44	6.25	7.75
15	41	Male	5.54	4.93	6.10	4.88	6.39	4.99	4.78
16	37	Female	7.42	7.32	7.17	7.18	7.34	7.33	7.17
17	48	Male	7.91	7.06	8.07	6.03	6.59	5.43	5.16
18	39	Female	5.71	5.15	5.76	4.94	5.66	4.88	5.37
19	52	Male	7.05	5.66	6.61	5.53	6.35	5.83	6.60
20	71	Male	6.14	6.16	5.94	5.94	6.07	6.21	6.32
21	58	Male	5.80	5.25	5.20	4.93	5.46	5.41	5.09
Mean	48.09		6.72	6.16	6.47	5.84	6.66	5.97	6.43

Table B3

Skin conductance level (SCL)*, for each of seven conditions (i.e., Pre-baseline, Narrative #1, Negative, Narrative #2, Positive, Narrative #3, Post-baseline) for each preschool-age child who stutters (CWS, n = 20, 15 male). Age is expressed in months, and SCL is expressed in microSiemens (µS).*

			Skin conductance level: Children who stutter (CWS)						
Participant	Age	Gender	Pre-baseline	Narrative #1	Negative	Narrative #2	Positive	Narrative #3	Post-baseline
1	37	Female	3.52	4.20	5.17	5.33	4.36	3.93	6.55
2	48	Male	13.70	24.01	37.45	30.09	32.27	37.51	38.69
3	43	Male	15.72	18.32	21.86	22.97	24.55	26.71	24.76
4	40	Male	29.02	31.73	34.29	37.67	38.47	36.77	32.40
5	42	Female	8.93	9.57	14.78	8.53	11.81	16.15	14.79
6	56	Male	7.54	11.47	10.66	12.25	9.09	15.43	13.17
7	36	Male	4.54	5.19	6.50	7.54	6.66	4.93	3.08
8	43	Male	10.88	12.68	25.35	24.69	30.09	27.82	29.27
9	44	Female	19.16	21.38	21.98	24.60	21.05	24.01	22.22
10	62	Male	2.67	2.43	3.71	5.42	5.82	4.50	7.13
11	50	Female	4.92	12.00	18.65	17.60	18.28	18.37	23.97
12	61	Male	6.02	8.26	11.25	11.53	12.90	13.42	14.32
13	38	Male	13.73	16.38	24.20	22.60	19.32	27.28	31.26
14	68	Male	6.09	7.75	8.64	8.72	10.08	10.36	11.56
15	71	Female	1.91	1.64	4.08	5.54	8.41	8.14	7.24
16	54	Male	14.11	16.69	22.68	23.41	29.06	28.82	27.56
17	36	Male	7.72	9.61	11.03	12.83	17.69	19.17	19.60
18	51	Male	11.56	15.47	12.89	15.20	11.85	13.38	10.88
19	54	Male	23.69	26.33	31.26	31.80	33.71	34.83	34.62
20	37	Male	8.84	8.54	15.98	14.20	18.94	18.88	22.52
Mean	48.55		10.71	13.18	17.12	17.13	18.22	19.52	19.78

Table B4

Skin conductance level (SCL)*, for each of seven conditions (i.e., Pre-baseline, Narrative #1, Negative, Narrative #2, Positive, Narrative #3, Post-baseline) for each preschool-age child who does not stutter (CWNS, n = 21, 11 male). Age is expressed in months, and SCL is expressed in microSiemens (μS).*

			Skin conductance level: Children who do not stutter (CWNS)						
Participant	Age	Gender	Pre-baseline	Narrative #1	Negative	Narrative #2	Positive	Narrative #3	Post-baseline
1	70	Male	12.30	15.32	17.82	18.39	20.89	19.85	19.91
2	47	Male	22.59	19.80	23.24	25.68	19.95	26.01	23.32
3	42	Female	6.35	9.37	9.95	10.72	9.37	11.64	12.63
4	41	Female	11.56	15.59	14.02	11.56	7.24	18.39	19.79
5	43	Female	15.69	18.21	18.22	18.86	16.58	18.02	16.85
6	43	Female	5.43	7.52	11.57	10.07	10.89	11.78	12.69
7	46	Female	8.42	9.77	10.97	9.94	10.90	9.94	10.95
8	37	Male	5.79	7.70	24.75	25.24	19.18	26.40	32.95
9	61	Male	5.75	10.59	10.43	15.52	10.42	16.47	15.88
10	42	Female	10.62	14.68	14.77	16.59	12.80	17.27	15.57
11	48	Male	9.31	12.34	15.16	13.24	12.60	14.05	15.58
12	47	Female	21.19	25.09	37.83	31.02	30.90	37.32	39.92
13	59	Male	6.42	10.28	12.73	12.18	12.48	13.81	13.75
14	38	Female	14.43	18.78	21.55	25.53	23.33	23.16	24.86
15	41	Male	7.73	6.82	8.48	6.39	6.74	7.44	7.55
16	37	Female	5.64	8.77	9.76	13.53	13.05	15.00	15.07
17	48	Male	1.87	3.06	4.56	4.30	5.06	5.90	4.83
18	39	Female	5.61	10.93	12.36	13.76	15.84	18.32	18.13
19	52	Male	17.12	18.19	18.21	19.39	19.93	20.43	15.17
20	71	Male	6.91	10.82	15.67	12.89	12.72	16.55	15.86
21	58	Male	7.08	10.76	13.47	14.26	16.42	17.04	16.81
Mean	48.09		9.90	12.59	15.50	15.67	14.63	17.37	17.53

Table B5

***Heart period (HP)**, for each of seven conditions (i.e., Pre-baseline, Narrative #1, Negative, Narrative #2, Positive, Narrative #3, Post-baseline) for each preschool-age child who stutters (CWS, n = 20, 15 male). Age is expressed in months, and HP is expressed in milliseconds (ms).*

			Heart period: Children who stutter (CWS)						
Participant	Age	Gender	Pre-baseline	Narrative #1	Negative	Narrative #2	Positive	Narrative #3	Post-baseline
1	37	Female	605.76	572.88	627.84	574.28	643.41	582.43	589.13
2	48	Male	633.13	601.29	653.06	554.39	652.24	558.96	580.43
3	43	Male	480.40	467.42	486.83	464.13	493.40	460.59	481.66
4	40	Male	629.06	633.39	719.45	578.99	675.57	568.70	693.59
5	42	Female	605.95	596.10	600.26	574.58	617.60	577.64	609.62
6	56	Male	748.57	683.52	715.68	661.03	730.91	639.76	714.92
7	36	Male	568.45	534.11	604.30	536.38	606.02	543.44	584.23
8	43	Male	525.40	509.53	524.74	493.31	522.70	506.43	521.94
9	44	Female	596.76	592.40	586.97	581.51	584.39	584.80	579.56
10	62	Male	700.03	642.09	711.87	599.86	721.25	607.83	674.72
11	50	Female	588.00	565.12	632.98	553.72	619.84	594.29	598.75
12	61	Male	602.50	591.47	647.32	562.21	619.39	537.40	596.41
13	38	Male	634.19	630.41	660.14	627.57	655.55	620.09	632.21
14	68	Male	766.95	703.64	803.83	678.87	810.07	679.17	800.26
15	71	Female	571.38	561.59	579.02	555.90	575.78	546.77	584.74
16	54	Male	624.91	573.27	664.92	564.90	680.02	550.79	652.86
17	36	Male	573.89	517.48	560.71	516.82	557.04	518.84	570.77
18	51	Male	512.53	503.87	535.81	490.52	533.57	492.34	509.10
19	54	Male	624.52	606.11	652.35	582.92	642.42	570.00	596.86
20	37	Male	546.93	544.11	523.02	508.31	526.01	507.25	513.20
Mean	48.55		606.97	581.49	624.56	563.01	623.36	562.38	604.25

Table B6

***Heart period (HP)**, for each of seven conditions (i.e., Pre-baseline, Narrative #1, Negative, Narrative #2, Positive, Narrative #3, Post-baseline) for each preschool-age child who does not stutter (CWNS, n = 21, 11 male). Age is expressed in months, and HP is expressed in milliseconds (ms).*

			Heart Period: Children who do not stutter (CWNS)						
Participant	Age	Gender	Pre-baseline	Narrative #1	Negative	Narrative #2	Positive	Narrative #3	Post-baseline
1	70	Male	587.65	584.03	539.64	558.55	585.69	553.69	572.78
2	47	Male	663.09	640.71	687.97	631.83	705.31	635.91	665.46
3	42	Female	618.23	590.09	574.00	567.72	596.64	554.40	593.22
4	41	Female	612.97	612.57	640.77	610.22	649.56	624.23	588.57
5	43	Female	555.72	544.70	589.07	524.73	550.66	548.62	571.75
6	43	Female	751.73	706.73	691.44	660.06	711.66	630.20	717.94
7	46	Female	776.51	679.75	746.32	673.31	758.85	651.28	720.54
8	37	Male	630.49	620.67	624.68	597.84	627.19	604.66	640.46
9	61	Male	696.68	630.33	712.15	606.47	733.24	599.42	694.09
10	42	Female	610.96	591.66	615.86	566.38	602.55	581.02	620.04
11	48	Male	676.10	622.03	684.45	589.87	673.38	602.69	673.31
12	47	Female	560.88	549.23	572.49	534.26	564.35	527.94	537.61
13	59	Male	636.28	642.21	684.99	634.02	768.70	628.30	691.50
14	38	Female	643.53	629.12	571.16	619.24	621.06	636.77	701.73
15	41	Male	566.37	559.44	578.76	546.73	591.04	547.37	535.55
16	37	Female	645.59	628.67	633.06	603.93	641.31	613.23	637.28
17	48	Male	689.13	664.81	718.06	624.22	679.95	585.04	599.65
18	39	Female	518.30	508.30	521.35	495.01	531.43	492.86	525.08
19	52	Male	609.80	553.69	599.19	525.18	572.50	541.54	593.12
20	71	Male	682.97	623.19	670.56	630.72	680.53	627.87	684.73
21	58	Male	653.28	609.95	630.39	586.66	638.71	588.58	633.23
Mean	48.09		637.44	609.14	632.68	589.85	642.11	589.32	628.46