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Differentiating Challenge Reactivity from Psychomotor Activity in Studies of Children's Psychophysiology: Considerations for Theory and Measurement

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Abstract

Current methods of assessing children's physiologic "stress reactivity" may be confounded by psychomotor activity, biasing estimates of the relation between reactivity and health. We examine the joint and independent contributions of psychomotor activity and challenge reactivity during a protocol for children ages 5–6 ($N=338$). Measures of parasympathetic (RSA) and sympathetic (PEP) reactivity were calculated for social, cognitive, sensory, and emotional challenge tasks. Reactivity was calculated relative to both resting and a paired comparison task that accounted for psychomotor activity effects during each challenge. Results indicated that comparison tasks themselves elicited RSA and PEP responses, and reactivity adjusted for psychomotor activity was incongruent with reactivity calculated using rest. Findings demonstrate the importance of accounting for confounding psychomotor activity effects on physiologic reactivity.

Keywords

psychophysiology; physiologic reactivity; stress reactivity; children; methodology; confound; autonomic nervous system; ANS; parasympathetic; RSA; sympathetic; PEP

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Individual differences in children's autonomic nervous system (ANS) reactivity are increasingly proposed to be key factors in the development and maintenance of mental and physical health problems (Beauchaine, 2001; Beauchaine, Gatzke-Kopp, & Mead, 2007; Boyce, 2006; Porges, 2007). Indeed, evidence has accumulated indicating that individual differences in ANS reactivity are associated with children's internalizing and externalizing psychopathology (Boyce et al., 2001; Calkins, Graziano, & Keane, 2007; Crowell et al., 2006; Kagan, 1994; Raine, Venables, & Mednick, 1997) and physical health (e.g., Boyce et al., 1995). Further, studies have shown that children's reactivity can moderate the effects of contextual risks on those outcomes (e.g., Boyce, 1996; Boyce et al., 1995; El-Sheikh, Harger, & Whitson, 2001; El-Sheikh et al., 2009; Leary & Katz, 2004; Obradovi, Bush, Stamperdal, Adler, & Boyce, 2010; Shannon, Beauchaine, Brenner, Neuhaus, & Gatzke-Kopp, 2007). However, despite significant interest in children's autonomic reactivity and abundant evidence that psychomotor activity elicited by child protocols can influence ANS reactivity (reviewed below), very few methodological studies have been conducted to determine whether children's psychomotor activity during challenge protocols is confounding the assessment of ANS reactivity to challenge (see Porges et al., 2007, for an exception). As a result, current methods may over- or underestimate the relations between reactivity to a challenge task and children's health. In order to adequately harness the explanatory power of child psychophysiology, a parsing of the psychomotor contributions to the reactivity measured in child challenge protocols is needed. In this paper we present a basis for refining and sharpening physiological data collection methods by examining the results from a novel protocol designed to test whether using challenge-specific comparison tasks can improve measurement of challenge reactivity in young children by adjusting for the confounding influence of psychomotor activity.

Physiologic Reactivity

Physiologic reactivity has been defined as an individual's physiologic response to a discrete, environmental stimulus, relative to a comparison or resting state (Matthews, 1986). Respiratory sinus arrhythmia (RSA) and pre-ejection period (PEP) are reliable indices of the parasympathetic nervous system (PNS) and sympathetic nervous system (SNS) influence on cardiac functioning, respectively, and have been validated through pharmacologic blockade in adults (e.g., Berntson et al., 1994; Sherwood, Allen, Obrist, & Langer, 1986). In the past decade, PEP and RSA have been further established as valid and reliable measures of autonomic activity in children and adolescents (Alkon et al., 2006; Calkins & Keane, 2004; Quigley & Stifter, 2006). RSA refers to fluctuations in heart rate related to the respiratory cycle and gated by efferent fibers of the vagus nerve. RSA is as an index of the PNS's capacity to regulate responses to positive and negative environmental demands, with acute changes in RSA occurring in conjunction with emotional experiences or self-regulatory efforts (Beauchaine, 2001; Porges, 1995, 2003). Porges (2007) maintains that increased vagal tone (reflected in RSA increases) supports social engagement behaviors, whereas withdrawal of vagal inputs (lifting the "vagal brake," reflected in decreases in RSA) supports the metabolic requirements for fight/flight responses by allowing excitatory sympathetic influences to operate relatively unopposed. PEP is an indirect measure of SNS activity and is the time interval from the ventricular depolarization to the opening of the

aortic valve and the onset of left ventricular ejection, that is, the period of isovolumetric contraction.

Researchers who study the early development of mental and physical health problems have been particularly interested in understanding children's reactivity to stressful challenges—situations that evoke adaptive responding. Much of extant literature uses the term “stress reactivity” to capture this concept, although it may not optimally reflect what is measured. An encounter with challenging stimuli might elicit stress responses from a range of domains, including social, cognitive, physical and emotional responses. Yet, measurement may include ANS response beyond the specific stressful challenges that reactivity protocols have been designed to assess because RSA and PEP are involved in multiple forms of “psychomotor activity,” which includes muscle or motor effects of both stressful and non-stressful psychological processes. These distinctions are not always easy to make, as preparing musculature for action is a major component of the “fight or flight” response, and any activation of physiology from resting state could be thought of as a stress response. However, in order to advance the theory and measurement of the ways in which physiologic change relates to adjustment, it may be important to differentiate aspects of physiologic change, parsing those driven largely by psychomotor activity from those elicited by challenge. We propose that measurement of physiologic reactivity to a challenge task reflects a combination of *challenge reactivity* due to the non-motoric task demands, such as coping with social stress, cognitive difficulty, aversive sensory stimuli, or fearful stimuli, and reactivity due to any *psychomotor activity* involved in engaging in the challenge task, such as gross motor movement, speech, attention, and social processes.

Gross motor behavior

Bodily movement such as the change from sitting to standing and physical exercise produces SNS activation and PNS withdrawal in adults (e.g., Berntson et al., 1994; Cacioppo, Uchino, & Berntson, 1994; Nakamura, Yamamoto, & Muraoka, 1993), and physical movement generates PNS withdrawal in infants (Bazhenova & Porges, 1997). Recently, Porges et al. (2007) showed that motor movement influences 3–6 year old children's autonomic responding during challenging tasks. Findings revealed that increases in physical activity during a crayon-and-paper maze task (relative to a video-watching baseline) related to synchronous decreases in RSA and heart period (HP), although this association disappeared when using an individual's residualized changes in physical activity, which are corrected for initial level of activity. Further, both group- and individual-level increases in physical activity during a rigorous bike pedaling task (relative to rest) were related to synchronous decreases in RSA and HP, leading Porges et al. to argue that only physical activity that involves major metabolic resource demand, such as bicycling, may confound individual ANS reactivity. However, Porges et al. assessed motor activity as measured by an Actigraph fastened around the wrist of children's dominant hand and did not assess activity effects on SNS reactivity.

Speech

Vocalization alters PNS and SNS measures in adults (Bernardi et al., 2000; Reilly & Moore, 2003; Sloan, Korten, & Meyers, 1991) and children (Donzella, Tottenham, & Gunnar, 2009;

Kleinow & Smith, 2006), as a result of changes in the respiratory cycle due to speaking (see Berntson, Cacioppo & Quigley, 1993; Berntson et al., 1997) and motor activity in the face and throat. Vocalization may thus also confound reactivity measures. For example, PEP responses differ when mental arithmetic is performed silently or verbally (Tomaka, Blascovich, & Swart, 1994) such that PEP decreased during talking conditions; and assessments of baseline RSA responses were lower when baseline periods involved talking than when they were silent (Donzella et al., 2009). Therefore, responses to challenge tasks that require speaking include potential psychomotor confounds that may lead to PEP *activation* and RSA *withdrawal* and may not accurately reflect “challenge reactivity.”

Attending

RSA changes in response to voluntary sustained attention during non-challenging visual fixation in infants (Richards, 1987) and college students (Berntson, Cacioppo, & Fieldstone, 1996). Therefore, challenge tasks involving visual fixation (such as those using movie clips as a medium for stimuli presentation) may be confounded due to ANS effects from attentional focus, especially if they are compared to resting states that don't involve visual fixation. Relatedly, the mixed findings with cognitive attention challenges may result in part from variation in demands for speaking or moving during tasks. Attention tasks can produce *increases* in RSA if the task does not require concurrent increases in physical activity (Jonsson & Hansson-Sandsten, 2008), such as silent arithmetic leading to increased RSA as compared to a baseline (Sahar, Shalev, & Porges, 2001). On the other hand, cognitive attention tasks that include motor activity such as verbal responses or using a keyboard have been found to be indexed by a *decrease* in RSA and PEP (Beauchaine, 2001; Berntson et al., 1996; Suess, Porges, & Plude, 1994). This inconsistency in the direction of RSA changes during attentional tasks may result from motor activity contributing to vagal withdrawal and counteracting the parasympathetic increase effects of attending. Further research is needed to clarify those relations, as well as to better understand the psychomotor effects of using visual attending stimuli such as films for reactivity paradigms.

Social processes

Social interaction or engagement is a complex phenomenon that is not clearly or consistently defined in the psychophysiological literature but is linked with autonomic responses (see Uchino, Cacioppo, & Kiecolt-Glaser, 1996 for review) and likely to alter reactivity in a manner not intentionally elicited by the task challenge (see Kamarck & Lovallo, 2003). PNS regulation via the vagus nerve, in particular, is proposed to be the visceromotor component of the social engagement system (Porges 2001, 2003), and RSA has been found to increase in response to non-threatening, positive social engagement (e.g., Bazhenova & Porges, 1997; Porges, 2001) and the social challenge of being left with an unfamiliar examiner (Heilman et al., 2008). It is important to discern whether unmeasured interpersonal components of challenge protocols are contributing to children's ANS response.

In summary, there is evidence to suggest that a portion of the observed change in RSA and PEP across challenges may be confounded by various aspects of psychomotor activity. Moreover, studies of children's psychophysiology have predominantly drawn upon methods developed with adult populations, which are able to limit psychomotor confounds

(restricting movement, speech, etc.). Yet studies with young children necessitate modification of adult methods to provide challenges that are developmentally appropriate, ecologically valid, and engaging. Child protocols involve some element of social engagement in order to enlist and maintain child participation, and young children must speak to answer questions rather than using a keyboard. Furthermore, young children are naturally active and unable to completely inhibit extraneous movement particularly in novel contexts. Thus, existing child reactivity protocols may not properly measure or account for the influence of various forms of psychomotor activity (Beauchaine, 2001; Fox, Schmidt, Henderson, & Marshall, 2007).

The Porges et al. (2007) study reviewed above provides a rare example of empirical efforts to address this issue. Additionally, a few researchers have measured motor activity during challenge tasks in order to control for group differences in movement in reactivity analyses (e.g., Butler et al., 2003; Crowell et al., 2006). However, establishing that two groups do not differ in their average level of movement does not eliminate the effects of movement on ANS reactivity at the level of individuals. Just as stressful stimuli do not affect individual children's physiology in a homogeneous manner, movement should not be expected to relate to individual children's ANS reactivity in a homogeneous way. Thus statistically controlling for movement (e.g., acceleration or number of utterances) during a challenge task is not likely to adequately address the confounding influence of movement on individual children's reactivity scores. Furthermore, because stress can affect children's rate of speech and restlessness, covarying the effect of each child's movement during challenges in analyses may actually remove variance of interest in the dependent variable. Therefore, it may be useful to separately measure the ANS responses to the motor activity embedded within challenging tasks and account for those effects in analyses.

Although much research claims to be measuring stress reactivity in children, if reactivity is calculated as task arousal minus resting state, the reactivity captured may partly reflect effects of psychomotor activity, such as normal levels of movement, speech, attention, and social engagement, rather than independent indices of "stress." In contrast, psychomotor activity sometimes leads to increases in RSA and PEP, which may attenuate effects. Figure 1 shows the hypothetical ways in which psychomotor activity and challenge responses contribute to ANS changes, which may create confounded challenge reactivity scores, including scenarios where:

- (I) the psychomotor demands of the task are arousing and the demands for coping with the challenge lead to additional ANS reactivity, rendering overall reactivity an *overestimation* of reactivity due to challenge;
- (II) the psychomotor demands of the task are calming but the demands for coping with the challenge lead to ANS reactivity, rendering overall reactivity an *underestimation* of reactivity due to challenge; and
- (III) the psychomotor demands of the task are arousing but the demands for coping with the challenge lead to an ANS calming response, rendering overall reactivity *misleading* by suggesting reactivity to the challenge when the challenge actually led to calming.

Disentangling which aspects of observed reactivity are due to “psychomotor activity” and which are due to “challenge reactivity” is critical to the study of reactivity. Adopting a more sophisticated and precisely controlled approach to reactivity measurement could advance theoretical understanding of neurobiological stress responses, offer greater predictive utility, and disarticulate challenge reactivity from extraneous or confounding influences.

Present Study

Based on the rationale presented above for the development of new methods of physiological data collection, we examined whether using *challenge-specific comparison tasks* could improve measurement of reactivity by differentiating the confounding influence of various forms of psychomotor activity commonly elicited by reactivity protocols. We augmented a standardized child reactivity protocol with four tasks representing social, cognitive, sensory and emotional domains to include challenge-specific comparison tasks designed to elicit the same psychomotor activity as that involved in the challenge tasks. This allowed us to assess effects of psychomotor activity on individual children’s ANS responding during each challenge. The research questions addressed were: 1) does the reactivity protocol for children differentiate the challenge reactivity from the ANS effects of the psychomotor activity required to complete the challenge?; 2) what effect does task-specific psychomotor activity have on overall ANS responding for each challenge task?; 3) what effect does each challenge have on overall ANS responding, after adjusting for task-specific psychomotor activity; and 4) how does reactivity adjusted for task-specific psychomotor activity compare to reactivity without this adjustment?

Method

Participants

Participants were a community sample of 338 typically developing children (163 females and 175 males) who participated in a larger, longitudinal study of social dominance status, biological responses to adversity, and child mental and physical health (see XXX, 2010, for a detailed description of study). Children with (1) a heart or circulation problem, (2) a serious handicap or (3) chronic illness were not eligible to participate. The children in the sample averaged 5.32 years of age at kindergarten entry ($SD = .32$; range: 4.75–6.28). The sample was ethnically diverse, with 19% African American, 11% Asian, 43% European or White, 4% Latino, 22% Multi-ethnic, and 2% identified as “other” ethnicity by their caregiver. Eighty-seven percent of primary caregivers who provided information on family and child characteristic were biological mothers, 9% biological fathers, 2.5% adoptive mothers, 0.6% biological grandmothers, and 0.9% “other” relations to the child (all caregivers are heretofore referred to as parents). Family demographic information was not provided by 16 families. Average annual household income ranged from less than \$10,000 to greater than \$400,000 ($M = \$60\text{--}79,999$; $Mdn = \$80\text{--}99,999$). Highest level of educational attainment in the household ranged from less than a high school diploma (8 individuals) to advanced degrees (145 individuals), with 75% of households having a member with at least a college degree.

Procedures

Participants were recruited in three waves from 29 kindergarten classrooms within 6 public schools in the XXX Area during the Falls of 2003, 2004, and 2005. Schools were selected to represent a variety of socio-demographic and ethnic/racial characteristics of the metropolitan area. Schools were provided with \$20 per child enrolled in the study. Parents' informed consent and children's assent were obtained prior to the start of the data collection, and participants were assured of the confidentiality of their responses. This study was approved by the Committee for the Protection of Human Subjects of the University of XXX.

The 20-minute reactivity protocol was completed by children in a separate, quiet room at their elementary school. The autonomic reactivity protocol started with a *resting* period when an experimenter read the child a non-emotional, neutral story (2 minutes). Next, the child completed four sets of paired tasks (one challenge, one comparison task each domain). The challenge tasks were designed to elicit autonomic responses to challenges across social, cognitive, sensory, and emotional domains for 4–6 year old children (Boyce et al., 1995; Alkon et al., 2003). Since the challenges involved some degree of potentially confounding psychomotor activity, for this study, each challenge task was preceded by a non-challenging “comparison task” that closely paralleled the psychomotor demands of that challenge task. Table 1 shows the order of the tasks. The *social challenge task* (2 minutes) was a structured interview about the child's family, friends, and likes/dislikes adapted from the Gesell School Readiness Screening Test (Carlson, 1985). This was preceded by the *social comparison task* in which children were asked to name the common animals and colors from a picture book to capture arousal associated with speaking, gestures during social speech, and attention involved in social engagement (2 minutes). The *cognitive challenge task* (2 minutes) was a digit span recitation task adapted from the Kaufman Assessment Battery for Children (Kaufman & Kaufman, 1983) in which the child was asked to recall sequences of numbers up to six digits in length and received corrections after making a mistake. This was preceded by the *cognitive comparison task* in which children were asked to repeat simple, one or two-digit number sequences to capture arousal associated with listening, speaking numbers, and social engagement (1 minute). The *sensory challenge task* (1 minute) was a taste-identification task (Kagan & Snidman, 1991) during which two drops of concentrated lemon juice were placed on the middle tip of the tongue, 10 and 30 seconds into the task; the child was asked to “taste something and tell me what it tastes like” after each set of drops. This was preceded by the *sensory comparison task* in which children were asked to identify two drops of water placed on the middle tip of their tongue to capture arousal associated with mouth opening and swallowing, anticipating, and guessing the content of the liquid (1 minute). The *emotional challenge task* (2 minutes) consisted of watching a short emotion-evoking movie clip chosen to elicit fear (Eisenberg et al., 1988). This was preceded by the *emotion comparison task* in which children were asked to watch an emotionally-neutral movie clip to capture physiological responding associated with attending to a visual stimulus (2 minutes). The reactivity protocol concluded with a second *resting* period involving the reading of another neutral story (2 minutes). Due to the prohibitively large sample required for the statistical power to counterbalance the order of tasks, all tasks were presented to each child in the same sequence.

Physiological Measures

Children's ANS reactivity was assessed using changes in both RSA and PEP in response to the series of challenges. Four spot electrodes (two current, two impedance) were placed in the standard tetrapolar configuration on the child's neck and chest, and ECG electrodes were placed on the right clavicle and lower left rib. A 4 micro Amp AC current at 100 kHz was passed through the two current electrodes, and Z_0 (basal thoracic impedance) and dZ/dt (first derivative of change in impedance over change in time) signals were acquired from the two impedance electrodes. ANS measures (HR, RSA, and PEP) were monitored continuously during the protocol. Data were acquired using the Biopac MP150 (Biopac Systems, Santa Barbara, CA) interfaced to a PC-based computer. The sampling frequency was 1 kHz. Analog data were continuously monitored on the computer for signal and noise, and digitized data were stored for off-line analysis. Prior to analyses, each waveform was verified and IBIs were visually checked and edited for artifacts using the MindWare software program (www.mindwaretech.com). Additionally, outlier data were checked and verified minute-by-minute for each ANS measure if they were $> 3 SD$ from the group mean. After review, roughly 8% of subjects had some data which required editing to remove artifact from IBI calculations (such as error due to child sneezing, electrode coming loose briefly, or child bumping electrode). RSA was estimated as the natural logarithm of the variance of heart period within the frequency bandpass associated with respiration at this age (i.e., 0.15 to 0.80 Hz) (Bar-Haim, Marshall, & Fox, 2000; Rudolph, Rudolph, Hostetter, Lister, & Siegel, 2003). PEP time intervals were calculated based on the time in milliseconds from the ECG Q-point (corresponding to the onset of ventricular depolarization) to the B-point of the dZ/dt waveform (corresponding to the onset of left ventricular ejection; Kelsey & Guethlein, 1990). Missing data were due to acquisition or scoring problems, such as equipment malfunction, research assistant error, extraneous movement, electrode misplacement or displacement; 97% of the 338 enrolled children had scorable ANS data ($N=329$).

Data Reduction and Analysis

Mean PEP and RSA magnitudes for each task were calculated for one-minute intervals and averaged within each task (Cacioppo et al., 1994). PEP and RSA means for resting story 1 and 2 are shown in Table 1. Mean PEP values for resting story 1 and 2 were strongly correlated, $r = .90$, and were not different, $t(314) = -1.21$, $n.s.$; $d = .03$. Although strongly correlated, $r = .79$, mean RSA values during resting story 1 were lower than those during story 2, $t(325) = -5.14$, $p < .01$; $d = .19$. However, the actual mean-difference and effect size were negligible, and there was variability in which story produced the lowest RSA values for children. Thus, for consistency, resting story 1 and 2 were averaged to create PEP and RSA resting story scores, heretofore referred to as "rest."

Three difference scores were calculated for each of the four task domains: "psychomotor activity" (challenge-specific comparison task – mean resting stories); "challenge reactivity" (challenge task – paired comparison task) and "overall task response" (challenge task – mean resting stories). See Figure 1 for a visual representation of these difference scores. Negative RSA and PEP difference scores reflect autonomic reactivity via PNS withdrawal and SNS activation, respectively. Although residualized change scores are sometimes used

to account for baseline value influences on change scores, difference scores and residual scores were very strongly correlated in these data ($r = .91-.99$). Thus, to aid interpretation of the disaggregated components of psychobiological reactivity, individual difference scores were used for analyses, and data are presented in their original metric.

To evaluate patterns in ANS response across the protocol, repeated measures ANOVAs were conducted for RSA and PEP scores over the series of tasks for the children with complete data. T-tests were used to assess whether the ANS change assessed via each of the three difference score calculations (psychomotor activity, challenges reactivity, and overall task responding) was different from zero. Paired *t*-tests were used to examine differences in reactivity derived from the three representations of difference scores and assess for the importance of using task-specific comparison tasks to account for psychomotor activity effects. Finally, ANOVAs were conducted to test for sex differences in the ANS measures of resting state, psychomotor activity, challenge reactivity and overall task responding.

Results

Table 1 presents the means, ranges, and standard deviations for RSA and PEP measures by task for each of the three RSA and PEP summary scores (psychomotor activity, challenge reactivity, and overall task response), which correspond to the conceptual line drawings *a*, *b*, and *c* in Figure 1. Table 2 presents correlations among scores for overall task responding and challenge reactivity for each task, within ANS measures. Overall task responding and challenge reactivity scores moderately to strongly correlated with each other. Within each ANS measure, RSA and PEP challenge reactivity was not correlated among the four domains, whereas RSA and PEP overall task responding was moderately to strongly correlated among all domains. The RSA and PEP task responses were unrelated to each other (all r 's $< .12$), suggesting that RSA and PEP scores, as expected, contribute uniquely to autonomic arousal relative to rest and psychomotor activity comparisons (Berntson et al., 1996).

Repeated Measures ANOVAs for reactivity protocol

Figure 2 presents average RSA and PEP responses to the comparison and challenge tasks. The repeated measures ANOVAs were corrected for violation of the sphericity assumption using Huynh-Feldt corrections for degrees of freedom and revealed significant condition effects for RSA, $F(9, 2844) = 89.97, p < .001; \epsilon = .76$; and PEP $F(9, 2655) = 8.24, p < .001; \epsilon = .65$. As illustrated in Figure 2, there were statistically significant changes between every set of adjacent tasks except 1 and 2 for RSA, indicating that, on average, parasympathetic activity changed between each comparison task and its paired challenge task and between each challenge task and the comparison task for the following domain. PEP also changed significantly between tasks 3 and 4, 5 and 6, 7 and 8, 8 and 9, indicating that, on average, sympathetic activity changed between the paired comparison and challenge tasks, and between each challenge task and the comparison task for the following domain. Such change suggests that this series of tasks elicited sample-level variability in PNS and SNS responding throughout the protocol and, thus, showed differentiation of challenge versus psychomotor

activity responses. Examination of the direction of the significant PEP and RSA changes in between tasks are detailed in analyses below.

Psychomotor activity

Column *a* in Table 1 shows the results of t-tests to determine whether, at the sample level, ANS responses to psychomotor activity were significantly different from zero. Relative to rest, there were significant changes during 3 of the 4 comparison tasks for RSA and 2 of 4 comparison tasks for PEP. The social comparison task (picture-naming) was the only comparison task that did not show significant mean-level RSA or PEP changes. The cognitive comparison task (number-repeat) was associated with significant decreases in RSA and PEP (PNS withdrawal and SNS activation). The sensory comparison task (water-taste) was associated with a significant increase in RSA (PNS augmentation), and the neutral movie was associated with increases in RSA and PEP (PNS augmentation and SNS decreases).

Challenge Reactivity

Column *b* in Table 1 shows the results of t-tests to determine whether, at the sample level, challenge reactivity was significantly different from zero. Recall that challenge reactivity is calculated relative to its paired comparison task, in order to account for the effects of psychomotor activity. RSA challenge reactivity was significantly different from zero during all four challenge tasks, such that the social and sensory challenges were associated with significant decreases in RSA (PNS withdrawal) and the cognitive and emotional challenges were associated with significant increases in RSA (PNS augmentation). PEP challenge reactivity was significantly different from zero during one challenge task such that the emotional challenge was associated with significant decreases in PEP (SNS activation).

Overall Task Response

Although not a central question of this study, for the interested reader, column *c* in Table 1 shows the results of t-tests to determine whether, at the sample level, overall task response was significantly different from zero.

Comparison of Psychomotor Activity and Challenge Reactivity

Paired t-tests revealed that (see Table 1 for means used for comparisons), for some tasks, the ANS change from rest levels to comparison tasks (psychomotor activity) was significantly greater in magnitude than the change from the comparison task to the challenge task (challenge reactivity). The psychomotor activity effects of the cognitive comparison task on RSA and PEP were greater than and in opposite direction than the challenge reactivity during that task, RSA: $t(325) = -17.95, p < .001$; PEP: $t(315) = -1.64, p = .100$. This suggests that listening to and repeating developmentally simple, single- and double-digit numbers led to different modes of ANS responding than the cognitive challenge of recalling and repeating increasingly complicated strings of multiple numbers while receiving corrective feedback. Similarly, the psychomotor activity effects of the emotion comparison task led to greater PEP changes than the challenge effects of the emotional task, $t(317) = 6.84, p < .001$, and these changes were in opposite directions. This suggests that visual and

auditory attending during a neutral film led to a different mode of SNS responding than watching a fear-inducing film. RSA challenge reactivity to the social and sensory challenge tasks was greater than the RSA response associated with their respective psychomotor activity comparison tasks, $t(323) = 3.31, p < .001$; $t(321) = 5.81, p < .001$. Psychomotor activity and challenge reactivity were not significantly different in magnitude for RSA during the emotional task or PEP for the social and sensory tasks.

Comparison of Challenge Reactivity and Overall Task Response

The differences in magnitude and direction of ANS responses that result from using psychomotor comparison tasks versus resting baselines can be seen by comparing columns *b* and *c* in Table 1. As can be seen, both challenge reactivity and overall task responding difference scores capture a range of physiological responses across all four domains, with a tendency for less variability when reactivity is calculated with psychomotor comparison tasks. Across both types of scoring, roughly half of the sample (32.5–68.5%) showed a decrease in PEP or RSA for each task suggesting a “stress” response to challenges in a substantial subset of the sample, regardless of calculation approach. These findings confirm that parsing out psychomotor activity effects on measures of RSA and PEP reactivity captured substantial variability in children’s PNS and SNS responses to challenges, as did the traditional approach.

In some instances, the physiologic effects captured via these two different calculations of reactivity were contrasting. Figure 3 illustrates two of the more striking differences found. Paired *t*-tests revealed that, during the number-recall task, RSA increased relative to the comparison task but decreased relative to rest, RSA: $t(325) = -16.24, p < .001$, and PEP did not change relative to the comparison task but decreased relative to rest, PEP: $t(315) = -2.13, p = .034$. This suggests that ANS psychomotor effects of speech, attention, and social engagement led to misleading cognitive challenge reactivity results, appearing to produce PNS withdrawal rather than PNS increases, as illustrated in the conceptual drawing in Figure 3-A. During the lemon-juice task, RSA decreases were greater relative to the comparison task than to rest, RSA: $t(320) = 2.83, p = .005$, suggesting that ANS psychomotor effects of awaiting a drop of liquid and swallowing led to an underestimation of challenge reactivity to the aversive sensation of lemon juice on the tongue. During the scary movie task, average PEP levels decreased relative to the comparison task (SNS activation) but increased relative to rest (SNS withdrawal), PEP: $t(316) = 6.55, p < .001$; and RSA increases were smaller relative to the neutral movie than to rest, RSA: $t(325) = 4.84, p < .001$. This suggests that ANS psychomotor effects of visual and auditory attending during movie-watching led to an underestimation of the challenge reactivity watching a scary movie, as illustrated in the conceptual drawing in Figure 3-B. Challenge reactivity and overall task responding were not significantly different in magnitude or direction for the social task RSA and PEP or sensory task PEP.

Sex Differences in ANS responses

The ANOVAs showed few differences in ANS measures by sex. Resting stories averages and psychomotor activity levels were not different by sex for either RSA or PEP. Challenge Reactivity and Overall Task Responses were not different by sex for RSA. PEP Emotional

Challenge Reactivity was greater for boys than for girls, $F(1, 315) = 6.80, p = .01$. PEP Cognitive Overall Task Responding, $F(1, 317) = 3.90, p = .05$, and Sensory Overall Task Responding $F(1, 310) = 5.12, p = .02$ was greater for girls than for boys. All other PEP summary scores were not different by sex. Collectively, only 3 out of 26 ANS scores (1 rest, 4 psychomotor activity, 4 challenge reactivity, and 4 overall task response scores for both RSA and PEP) showed sex differences, without corrected p-values for the number of tests conducted, and without consistency in which task they occurred for, suggesting that sex differences were not a major factor in this study.

Discussion

Using a series of paired comparison and challenge tasks in a reactivity protocol with a sample of 5–6 year old children, this study revealed that comparison tasks involving psychomotor activity such as speech, visual focusing, attending, and/or social engagement led to significant ANS responses. Additionally, our findings showed that calculating reactivity with adjustments for the effects of challenge-specific psychomotor activity yields different findings than calculating reactivity without such adjustments. These results highlight the importance of considering the degree to which psychomotor effects contribute to challenge reactivity.

The values of rest and reactivity in these data parallel those found in other published studies using similar samples and measures (e.g., Alkon et al., 2003; Allen & Matthews, 1997; Quigley & Stifter, 2006) and suggest that both comparison and challenge task demands produced meaningful physiological responses throughout the protocol in both branches of the ANS. The significant variability in responses to tasks provides additional evidence that this was an appropriate protocol for examining ANS differences in this age group (Kamarck & Lovallo, 2003).

It is important to note that, for the majority of tasks, task psychomotor activity demands led to significant RSA and PEP changes. Given the literature that suggests that speech production affects ANS (Bernardi et al., 2000; Reilly & Moore, 2003; Sloan et al., 1991), it was surprising that RSA and PEP during the cognitive comparison task (i.e. saying numbers) were different from rest, but RSA and PEP during the social comparison task (i.e. saying animal and color names) were not. Challenge-specific modalities of speech may draw upon different neural circuitry and thus may impact ANS differently (Berntson et al., 1996). Accordingly, it may be that the motor action involved in non-challenging, conversational speech does not affect the PNS or SNS, whereas listening to and repeating simple numbers leads to SNS and PNS reactivity. Of course, it is also possible that, although the cognitive comparison task was designed to be non-challenging for this age group, some children beginning kindergarten may have found repeating even single digit numbers to be difficult. If this were the case, then the challenge reactivity score for those children would be an underestimate of their challenge response.

Furthermore, both the sensory comparison and the emotional comparison tasks led to ANS calming responses, relative to rest. Both the act of quietly awaiting and swallowing a drop of water and the act of viewing a neutral movie consist of quiescent behavioral states with

decreased metabolic demands (see Porges, Doussard-Roosevelt, Portales, & Greenspan et al., 1996) and increased need for attending behaviors (Richards, 1987), which are consistent with increases in RSA and PEP. The contrasting patterns of psychomotor activity across the four task domains provide support for our premise that comparison tasks must be challenge-specific to properly account for psychomotor demands of particular challenges.

These findings are relevant to the argument that engaging children in some minimal manner is necessary to limit movement artifact in ANS measures of rest (see Fox et al., 2007). “Resting baseline” has been assessed as children were read a relaxing story (Alkon et al., 2003; ages 3–5), were shown a neutral movie (Calkins et al., 2007; age 2) or a screen with changing shapes (Gilissen et al., 2007; ages 3–4), and were spoken to by the experimenter (Quigley & Stifter, 2006; ages 4–5). These researchers acknowledge that such assessments do not capture true rest, given that the child is engaged in an external stimulus, but contend that such engagement does not elicit affect or motor activity and thus constitutes a reasonable reference point for assessing reactivity. Yet, our data suggest that this depends on the psychomotor activity elicited by the movement-inhibiting baseline condition. Because ANS activity during the social comparison task was not different from resting story levels, use of social engagement to keep a child calm and focused, such as reading a story, may be an appropriate baseline for social challenges. Our findings also provide support for the increasing use of neutral videos as reference values for reactivity to arousing films for children (e.g., Gilissen et al., 2007) and adults (e.g., Rottenberg, Salomon, Gross, & Gotlib, 2005). However, using a video as a baseline for non-video challenges (e.g., Porges et al., 2007) may misrepresent children’s resting states because attending to a video leads to a calming response. This may be particularly problematic because the neutral movie did not affect all children’s ANS uniformly, and it would enhance apparent reactivity scores for some children who would not be identified as highly reactive relative to a true resting baseline.

Additionally, our results demonstrate that significant individual variability in challenge reactivity can be observed, even after adjusting for psychomotor activity through the use of challenge-specific comparison tasks. Patterns of challenge reactivity were sometimes concordant with and sometimes in contrast to reactivity measured in existing studies. For example, relative to a talking baseline, the social challenge of engaging in dialogue with an adult stranger related to PNS withdrawal, which parallels the results from the only other published study with children of which we are aware that used a talking baseline (Bar-Haim, Fox, VanMeenen, & Marshall, 2004). These results were also consistent with suggestions that reactive withdrawal of RSA may serve to enhance attention to environmental stimuli so the individual can better match his or her behavioral and emotional response to the context (Porges et al., 1996). Yet our finding contrasts with that of Heilman et al. (2008) who found PNS activation in response to a “social challenge” that asked children to remain silent as they participated in a hearing test. Porges (2003, 2007) has posited that social challenges may affect ANS differently depending upon “neural” evaluations of threat in the environment. For example, if threat is perceived in the social interaction, the vagal brake will lift (PNS withdrawal), allowing sympathetic mechanisms to dominate as a means of maintaining fight or flight behaviors. On the other hand, if the social interaction is perceived

as safe, RSA may increase to support social engagement, such as focused listening. Our findings suggest heightened challenge reactivity to the social interview for this sample.

It is intriguing that adjusting for the influence of speaking numbers to an examiner resulted in sample-level PEP and RSA “calming responses” to the number challenge. Unlike some adult protocols that evoke stress by emphasizing speed and performance (e.g., Berntson et al., 1996), our number challenge was designed to be free of emotional stress. It may be that the cognitive challenge activated a predominantly attentional response for most children. Such an interpretation is commensurate with findings of PNS activation during silent arithmetic (Sahar et al., 2001). In contrast, overall task responses suggest that children were reactive to the number challenge for both PEP and RSA, which is in keeping with findings from cognitive attention tasks that include motor activity (e.g., Beauchaine, 2001; Berntson et al., 1996; Suess et al., 1994). It is likely that motor activity during cognitive challenges contributes to vagal withdrawal, which counteracts the PNS increase effects of attending and creates misleading ANS scores. If so, adjusting for those effects will clarify relations between cognitive challenge and reactivity.

After adjusting for psychomotor activity, the sensory challenge of tasting concentrated lemon juice produced the greatest PNS withdrawal in the study as well as SNS activation in over half of the children. This pattern of findings is consistent with those from previous use of this task with this age group (Alkon et al., 2003; Kagan & Snidman, 1991). Because the task’s psychomotor activity effects led to PNS and SNS calming, reactivity calculated relative to rest was attenuated, highlighting the need for psychomotor comparisons in this type of task, as well.

Given how uncommon it is to find PEP reactivity in research with young children (see Quigley & Stifter, 2006), it is noteworthy that adjusting for psychomotor activity resulted in significant sample-level SNS activation to an emotional challenge. Though the social, cognitive, and sensory tasks did not evoke a significant sympathetic response at the group level, nearly half of the subjects responded with SNS activation during those tasks, relative to comparison tasks, suggesting that the protocol captured meaningful individual variability in reactivity. The previously observed lack of PEP reactivity in young children may thus be due, in part, to the absence of appropriate adjustments for psychomotor activity and underestimated effects.

Using task-specific comparisons can be burdensome, so the question arises as to whether their use provides unique information, relative to that found using the traditional comparison to rest. Indeed, the two approaches often produced incongruent patterns of reactivity. In some cases, using challenge-specific comparisons, rather than the resting stories, attenuated reactivity scores (RSA social challenge, PEP cognitive challenge) and in other cases it enhanced reactivity scores (RSA sensory challenge; PEP sensory challenge). Even more concerning were circumstances in which one approach produced a response indicative of stressful arousal, while the other produced a calming response—creating opposite ANS response patterns, as illustrated in Figure 3. Moreover, although there was some overlap in the ANS change captured through both methods, challenge reactivity was not highly correlated with the more conventional method of calculating reactivity relative to rest. This

suggests that ANS responses due to psychomotor activity were not uniform across children and varied in their contributions to individual overall reactivity scores. This finding may have implications for the approach of controlling for motor effects in reactivity analyses by covarying acceleration or number of utterances (e.g., Butler et al., 2003; Crowell, 2006), because that approach presumes movement affects each child's physiology in a homogeneous manner. Adjusting for the ANS effects of each child's propensity for movement or talking using a paired psychomotor comparison may be of greater utility.

Strengths and Limitations

The novel methodological design was a major strength of this study, as was the inclusion of a large, ethnically diverse sample of kindergarten children. Yet notable limitations within this study highlight important directions for future research. First, because children's restlessness during an unstructured silent 2 minute period was likely to interfere with our ability to measure true rest, children were read a neutral story during the rest assessment. Although we believe that doing so improved our ability to limit extraneous movement and provided a quality measure of rest, evidence with 7-year-old children suggests that even listening to a neutral story can lower vagal tone slightly (Bar Haim et al., 2004). Relatedly, as other researchers have acknowledged (Alkon et al., 2003; Quigley & Stifter, 2006), children's limited ability to endure long protocols prevented us from introducing between-task recovery periods. There is thus some possibility that the lack of rests between challenge tasks and subsequent comparison tasks for the next domain confounded ANS measurements. However, because PEP is known to return to baseline after 20 seconds and RSA after one second (Berntson et al., 1997), the transition time between sets of tasks may have provided adequate recovery time for most children. Further, the lack of correlation between challenge reactivity scores suggests that arousal during one task did not influence reactivity in other tasks. Another important limitation to note is that, although we utilized psychomotor comparison tasks, no direct measures of movement or speech articulation were obtained in this research. Future studies that include assessments such as actigraphy or number of verbal utterances will allow for advanced comparison of psychomotor activity in challenge and comparison tasks and may provide information to refine these types of protocols. Finally, an important endeavor for future research will be to examine the relations between the various difference score calculations in this study and objective measures of child performance on the tasks or subjective reports of stress experienced during the challenges, as those important questions were beyond the scope of this paper.

Implications and Conclusions

These results have noteworthy implications for study design. Findings emphasize the importance of using challenge-specific comparisons, particularly for tasks that demonstrate psychomotor effects on ANS that are in opposition to the challenge effects on ANS, such as viewing scary movies. Additionally, findings suggest caution when aggregating physiologic data. The four domains of reactivity calculated with the shared baseline value of rest were modestly to strongly positively correlated for both RSA and PEP, which is consistent with findings from many studies that use a variety of tasks (e.g. Calkins & Keane, 2004; Quigley & Stifter, 2006; Salomon, Matthews, & Allen, 2000). In contrast, the four domains of reactivity calculated with comparison tasks were virtually uncorrelated, for both RSA and

PEP. This indicates that, after accounting for relevant psychomotor activity effects, challenge tasks actually evoked dissimilar modes or levels of autonomic responding (Bernston et al., 1996). Decisions about aggregation should depend heavily on theory, yet researchers should also carefully consider psychomotor activity across tasks and design appropriate baseline tasks to adjust for that. Averaging reactivity scores across a range of tasks (i.e., several cognitive stressors) or several tasks in a category (i.e. social tasks; see Chen et al., 2002) may be a useful strategy if tasks are indeed eliciting similar autonomic responses. Alternatively, compositing tasks that draw from different conceptual domains and tap different types of stress responses may be helpful to create an index of “general stress reactivity” across a range of situations. For example, XXX et al. (2010) found that a multi-domain composite of stress reactivity, adjusted for psychomotor activity, moderated the effects of contextual risk on developmental outcomes. However, aggregating multiple domains of reactivity calculated relative to rest without considering the possibly varying effects of psychomotor activity could be problematic. In fact, our results introduce the possibility that, rather than maximizing effects of individual differences in “stress reactivity,” researchers have been aggregating measurement error among tasks that were highly correlated because of shared baseline reference values and a lack of adjustment for the effects of psychomotor activity. For the average study in ANS literature, only about 25% of comparisons are significant in the hypothesized direction (Kamarck & Lovallo, 2003). Failure to attend to the psychomotor demands in protocols may account for inconsistent results in studies using subjects of all ages.

These results also may point to considerations for theory. Researchers should attend to whether their guiding theory about reactivity demands differentiation of aspects of reactivity. For example, youth’s desire for acceptance has been shown to predict heightened reactivity to a stressful social interview (Chen, Matthews, Solomon, & Ewart, 2002), and researchers may want to adjust for this effect when testing cognitive stress hypotheses using a cognitive task that involves social interaction. On the other hand, researchers interested in capturing this additional source of social stress during a social challenge may not wish to remove those effects. Also, challenge-specific comparisons may be indicated for certain measures of autonomic arousal and not others. Perhaps including ANS effects of attention and social engagement makes sense for a measure such as RSA, which is thought to index a precautionary response to prepare for mobilization *if* risk is detected (Porges, 2003, 2007), whereas differentiating stress responding may be warranted for a measure thought to reflect “fight or flight” responding, such as PEP.

Moreover, future investigations should attempt to elucidate those contexts in which challenge reactivity scores have more predictive utility for specific, ecologically valid outcomes than do overall task response scores. It is possible that overall task responding is a better predictor of children’s general mental and physical health, because the magnitude of children’s physiological responses to social engagement, attention, and talking may all contribute to those outcomes. Yet, adjusting for psychomotor activity may be particularly relevant when testing hypotheses based on theories that posit unique reactivity to a specific challenge or a stressor, rather than general reactivity to the environment, matters for children’s development. Although using one standard rest measure as a “baseline” may be

more pragmatic than using multiple task-specific comparisons, illuminating the subtleties in reactivity that predict variability in children's adjustment outcomes is an important endeavor.

Careful consideration of the conceptual and measurement issues in autonomic reactivity may be a precondition for evaluating existing research and for designing methodologically sound future research. These findings highlight scenarios in which psychomotor confounds markedly alter reactivity measurement and indicate that accurate assessment of ANS reactivity may demand pairs of comparison and challenge tasks that share psychomotor qualities. More precise measurement of reactivity is likely to help us understand which children are most reactive to stressful environments and how this affects adaptation.

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References

- Alkon A, Goldstein L, Smider N, Essex M, Boyce W, Kupfer D. Developmental and contextual influences on autonomic reactivity in young children. *Developmental Psychobiology*. 2003; 42:64–78. [PubMed: 12471637]
- Alkon A, Lippert S, Vujan N, Rodriquez M, Boyce WT, Eskenazi B. The ontogeny of autonomic measures in 6- and 12-month old infants. *Developmental Psychobiology*. 2006; 48:197–208. [PubMed: 16568414]
- Allen MT, Matthews KA. Hemodynamic responses to laboratory stressors in children and adolescents: The influence of age, race, and gender. *Psychophysiology*. 1997; 34:329–339. [PubMed: 9175447]
- Bar-Haim Y, Fox N, VanMeenen K, Marshall P. Children's narratives and patterns of cardiac reactivity. *Developmental Psychobiology*. 2004; 44:238–249. [PubMed: 15103734]
- Bar-Haim Y, Marshall P, Fox N. Developmental changes in heart period and high-frequency heart period variability from 4 months to 4 years of age. *Developmental Psychobiology*. 2000; 37:44–56. [PubMed: 10937660]
- Bazhenova OV, Porges SW. The Integrative Neurobiology of Affiliation. *Annals of the New York Academy of Sciences*. 1997; 807:469–471. [PubMed: 9071371]
- Beauchaine T. Vagal tone, development, and Gray's motivational theory: toward an integrated model of autonomic nervous system functioning in psychopathology. *Development and Psychopathology*. 2001; 13:183–214. [PubMed: 11393643]
- Beauchaine T, Gatzke-Kopp L, Mead H. Polyvagal theory and developmental psychopathology: Emotion dysregulation and conduct problems from preschool to adolescence. *Biological Psychology*. 2007; 74:174–184. [PubMed: 17045726]
- Bernardi L, Wdowczyk-Szulc J, Valenti C, Castoldi S, Passino C, Spadacini G, et al. Effects of Controlled Breathing, Mental Activity and Mental Stress With or Without Verbalization on Heart Rate Variability. *Journal of the American College of Cardiology*. 2000; 35:1462–1469. [PubMed: 10807448]
- Berntson G, Bigger J, Eckberg D, Grossman P, Kaufman P, Malik M, et al. Heart rate variability: Origins, methods, and interpretive caveats. *Psychophysiology*. 1997; 34:623–648. [PubMed: 9401419]

- Berntson G, Cacioppo J, Binkely P, Uchino B, Quigley K, Fieldstone A. Autonomic cardiac control. III. Psychological stress and cardiac response in autonomic space as revealed by pharmacological blockades. *Psychophysiology*. 1994; 31:599–608. [PubMed: 7846220]
- Berntson G, Cacioppo J, Fieldstone A. Illusions, arithmetic, and the bidirectional modulation of vagal control of the heart. *Biological Psychology*. 1996; 46:1–17. [PubMed: 8906354]
- Berntson G, Cacioppo J, Quigley K. Respiratory sinus arrhythmia: Autonomic origins, physiological mechanisms, and psychophysiological implications. *Psychophysiology*. 1993; 30:183–196. [PubMed: 8434081]
- Boyce, WT. Biobehavioral reactivity and injuries in children and adolescents. In: Bornstein, MH.; Genevro, J., editors. *Child development and behavioral pediatrics: Toward understanding children and health*. Mahwah, New Jersey: Erlbaum; 1996.
- Boyce, WT. Biology and context: Symphonic causation and the origins of childhood psychopathology. In: Cicchetti, D.; Cohen, DJ., editors. *Developmental Psychopathology: Developmental Neuroscience*. Vol. II. Hoboken, New Jersey: Wiley & Sons; 2006. p. 797-817.
- Boyce WT, Chesney M, Alkon-Leonard A, Tschann J, Adams S, Chesterman B, et al. Psychobiologic reactivity to stress and childhood respiratory illnesses: Results of two prospective studies. *Psychosomatic Medicine*. 1995; 57:411–422. [PubMed: 8552730]
- Boyce WT, Quas J, Alkon A, Smider N, Essex M, Kupfer DJ. Autonomic reactivity and psychopathology in middle childhood. *British Journal of Psychiatry*. 2001; 179:144–150. [PubMed: 11483476]
- Butler EA, Egloff B, Wilhelm FH, Smith NC, Erickson EA, Gross JJ. The social consequences of expressive suppression. *Emotion*. 2003; 3:48–67. [PubMed: 12899316]
- Cacioppo J, Uchino B, Berntson G. Individual differences in the autonomic origins of heart rate reactivity: The psychometrics of respiratory sinus arrhythmia and preejection period. *Psychophysiology*. 1994; 31:412–419. [PubMed: 10690921]
- Calkins SD, Graziano PA, Keane SP. Cardiac vagal regulation differentiates among children at risk for behavioral problems. *Biological Psychology*. 2007; 74:144–153. [PubMed: 17055141]
- Calkins SD, Keane SP. Cardiac vagal regulation across the preschool period: Stability, continuity, and implications for childhood adjustment. *Developmental Psychobiology*. 2004; 45:101–112. [PubMed: 15505799]
- Carlson, R. Gesell School Readiness Test. In: Keyser, D.; Sweetland, R., editors. *Test critiques*. Kansas City, KS: Test Corporation of America; 1985.
- Chen E, Matthews K, Solomon K, Ewart C. Cardiovascular reactivity during social and nonsocial stressors: Do children's personal goals and expressive skills matter? *Health Psychology*. 2002; 21:16–24. [PubMed: 11846340]
- Crowell S, Beauchaine TP, Gatzke-Kopp L, Sylvers P, Mead H, Chipman-Chacon J. Autonomic correlates of attention-deficit/hyperactivity disorder and oppositional defiant disorder in preschool children. *Journal of Abnormal Psychology*. 2006; 115:174–78. [PubMed: 16492108]
- Donzella, B.; Tottenham, N.; Gunnar, MR. Is that as stress response, or was I just talking? The importance of controlling for speech conditions during the TSST. Symposium conducted at the biannual meeting of the Society for Research in Child Development; Denver, CO. Apr. 2009
- Eisenberg N, Fabes R, Bustamante D, Mathy R, Miller P, Lindholm E. Differentiation of vicariously induced emotional reactions in children. *Developmental Psychology*. 1988; 24:237–146.
- El-Sheikh M, Harger J, Whitson SM. Exposure to interparental conflict and children's adjustment and physical health: The moderating role of vagal tone. *Child Development*. 2001; 72:1617–1636. [PubMed: 11768136]
- El-Sheikh M, Kouros C, Erath S, Cummings E, Keller P, Staton L. Marital conflict and children's externalizing behavior: Interactions between parasympathetic and sympathetic nervous system activity. *Monographs of the Society for Research in Child Development*. 2009; 74(1)
- Fox, NA.; Schmidt, LA.; Henderson, HA.; Marshall, PJ. Developmental Psychophysiology: Conceptual and Methodological Issues. In: Cacioppo, JT.; Tassinary, LG.; Berntson, G., editors. *Handbook of Psychophysiology*. New York: Cambridge University Press; 2007. p. 453-481.
- Gilissen R, Koolstra C, van Ijzendoorn M, Bakermans-Kranenburg M, van der Veer R. Physiological reactions of preschoolers to fear-inducing film clips: Effects of temperamental fearfulness and

- quality of the parent-child relationship. *Developmental Psychobiology*. 2007; 49:187–195. [PubMed: 17299791]
- Heilman KJ, Bal E, Bazhenova O, Sorokin Y, Perlman SB, Hanley MC, et al. Physiological responses to social and physical challenges in children: Quantifying mechanisms supporting social engagement and mobilization behaviors. *Developmental Psychobiology*. 2008; 50:71–182.
- Jennings JR. Editorial policy on analyses of variance with repeated measures. *Psychophysiology*. 1987; 24:474–475.
- Jonsson P, Hansson-Sandsten M. Respiratory sinus arrhythmia in response to fear-irrelevant and fear-relevant stimuli. *Scandinavian Journal of Psychology*. 2008; 49:123–131. [PubMed: 18352981]
- Kagan, J. Galen's prophecy. New York: basic; 1994.
- Kagan J, Snidman N. Temperamental factors in human development. *American Psychologist*. 1991; 6:856–862. [PubMed: 1928938]
- Kaufman, A.; Kaufman, N. Kaufman Assessment Battery for Children. Circle Pines, MN: American Guidance Service; 1983.
- Kamarck TW, Lavallo WR. Cardiovascular reactivity to psychological challenge: Conceptual and measurement considerations. *Psychosomatic Medicine*. 2003; 65:9–21. [PubMed: 12554812]
- Kelsey RM, Guethlein W. An evaluation of the ensemble averaged impedance cardiogram. *Psychophysiology*. 1990; 27:24–33. [PubMed: 2339185]
- Kleinow J, Smith A. Potential interactions among linguistic, autonomic, and motor factors in speech. *Developmental Psychobiology*. 2006; 48:275–287. [PubMed: 16617462]
- Leary A, Katz LF. Coparenting, family-level processes, and peer outcomes: The moderating role of vagal tone. *Development and Psychopathology*. 2004; 16:593–608. [PubMed: 15605627]
- Matthews, KA. Summary, conclusions and implications. In: Matthews, KA.; Weiss, SM.; Detre, T., editors. *Handbook of Stress, Reactivity and Cardiovascular Disease*. New York: Wiley-Interscience; 1986.
- Nakamura U, Yamamoto Y, Muraoka I. Autonomic control of heart rate during physical exercise and fractal dimension of heart rate variability. *Journal of Applied Physiology*. 1993; 74:875–881. [PubMed: 8458809]
- Obradovi J, Bush NR, Stamperdahl J, Adler N, Boyce WT. Biological Sensitivity to Context: Stress Reactivity Moderates the Relation between Contextual Adversity and Socio-Emotional and Cognitive Development. *Child Development*. 2010; 81:270–289. [PubMed: 20331667]
- Porges SW. Orienting in a defensive world: mammalian modifications of our evolutionary heritage: a polyvagal theory. *Psychophysiology*. 1995; 32:301–18. [PubMed: 7652107]
- Porges SW. The polyvagal theory: phylogenetic substrates of a social nervous system. *International Journal of Psychophysiology*. 2001; 42:123–146. [PubMed: 11587772]
- Porges SW. The polyvagal theory: phylogenetic contributions to social behavior. *Physiology and Behavior*. 2003; 79:503–513. [PubMed: 12954445]
- Porges SW. The polyvagal perspective. *Biological Psychology*. 2007; 74:174–184. [PubMed: 17045726]
- Porges SW, Doussard-Roosevelt JA, Portales AL, Greenspan SI. Infant regulation of the vagal 'brake' predicts child behavior problems: a psychobiology model of social behavior. *Developmental Psychobiology*. 1996; 29:697–712. [PubMed: 8958482]
- Porges SW, Heilman KJ, Bazhenova O, Bal E, Doussard-Roosevelt JA, Koledin M. Does motor activity during psychophysiological paradigms confound the quantification and interpretation of heart rate and heart rate variability measures in young children? *Developmental Psychobiology*. 2007; 49:485–495. [PubMed: 17577232]
- Quigley K, Stifter C. A comparative validation of sympathetic reactivity in children and adults. *Psychophysiology*. 2006; 43:116–143.
- Raine A, Venables PH, Mednick SA. Low resting heart rate at age 3 years predisposes to aggression at age 11 years: evidence from the Mauritius Child Health Project. *Journal of American Academy of Child and Adolescent Psychiatry*. 1997; 36:1457–1464.
- Reilly KJ, Moore CA. Respiratory sinus arrhythmia during speech production. *Journal of Speech, Language, and Hearing Research*. 2003; 46:164–177.

- Richards J. Infant visual sustained attention and respiratory sinus arrhythmia. *Child Development*. 1987; 58:488–496. [PubMed: 3829789]
- Rottenberg J, Salomon K, Gross J, Gotlib IH. Vagal withdrawal to a sad film predicts subsequent recovery from depression. *Psychophysiology*. 2005; 42:277–281. [PubMed: 15943681]
- Rudolph, CD.; Rudolph, AM.; Hostetter, MK.; Lister, GL.; Siegel, NJ. *Rudolph's Pediatrics*. 21. New York: McGraw Hill Medical; 2003.
- Sahar T, Shalev A, Porges S. Vagal modulation of responses to mental challenge in posttraumatic stress disorder. *Biological Psychiatry*. 2001; 49:637–643. [PubMed: 11297721]
- Salomon K, Matthews K, Allen M. Patterns of sympathetic reactivity in a sample of children and adolescents. *Psychophysiology*. 2000; 37:842–849. [PubMed: 11117464]
- Shannon KE, Beauchaine TP, Brenner SL, Neuhas E, Gatzke-Kopp L. Familial and temperamental predictors of resilience in children at risk for conduct disorder and depression. *Developmental Psychopathology*. 2007; 19:710–727.
- Sherwood A, Allen MT, Obrist PA, Langer AW. Evaluation of beta-adrenergic influences on cardiovascular and metabolic adjustments to physical and psychological stress. *Psychophysiology*. 1986; 23:89–104. [PubMed: 3003780]
- Sloan RP, Korten JB, Meyers MM. Components of heart rate reactivity during mental arithmetic with and without speaking. *Physiology and Behavior*. 1991; 50:1039–1045. [PubMed: 1805266]
- Suess PE, Porges SW, Plude DJ. Cardiac vagal tone and sustained attention in school-age children. *Psychophysiology*. 1994; 31:17–22. [PubMed: 8146250]
- Tomaka J, Blascovich J, Swart L. Effects of vocalization on cardiovascular and electrodermal responses during mental arithmetic. *International Journal of Psychophysiology*. 1994; 18:23–33. [PubMed: 7876036]
- Uchino BN, Cacioppo JT, Kiecolt-Glaser JK. The relationship between social support and physiological processes: A review with emphasis on underlying mechanisms and implications for health. *Psychological Bulletin*. 1996; 119:488–531. [PubMed: 8668748]

HIGHLIGHTS

Assessment of child “stress reactivity” may be confounded by psychomotor activity

“Non stressful” comparison tasks themselves elicited RSA and PEP responses

Reactivity adjusted for psychomotor activity was incongruent with traditional react.

It is important to account for confounding psychomotor activity effects

Refinement of assessment of child physiologic reactivity may improve prediction

Figure 1.

Graphic representation of the potential contributions of various components of Autonomic Nervous System (ANS) responding during control and challenge tasks.

Figure 2.

Respiratory Sinus Arrhythmia (RSA) and Pre-ejection Period (PEP) activity across 10 blocks of the reactivity protocol.

Note: Decreases in RSA and PEP scores reflect autonomic reactivity via PNS withdrawal and SNS activation, respectively. Standard Errors for RSA means ranged from .062–.069 and for PEP means ranged from .361–.382.

* indicates that the ANS measure changed significantly between the adjacent tasks ($p < .05$)

Conceptual Drawing of PNS Effects during Cognitive Domain

D:\ranjitha\Title Page (Bush et al.) Differentiating
P_s Conceptual Drawing of SNS Effects during Emotional Domain**Figure 3.**

Inconsistencies between two calculations of ANS difference scores: comparisons of contrasting reactivity calculation values (on the left) and conceptual drawings of the potentially misleading effects (on the right). For the Cognitive Challenge task (A), **a** leads to reactivity and **b** leads to calming, therefore **c** is misleading suggesting reactivity. For the Emotional Challenge task (B), **a** leads to calming and **b** leads to reactivity, therefore **c** is misleading suggesting calming.

Table 1
Descriptives for ANS measures: Task-level arousal and 3 Difference Scores of ANS responding

										(a)		(b)		(c)	
Respiratory Sinus Arrhythmia:										Psychomotor Activity (comparison – rest)		Challenge Reactivity (challenge – comparison)		Overall Task Response (challenge – rest)	
Task-level RSA index										mean difference	SD	sig	mean difference	SD	sig
Domain	Block	Task Condition	Mean	(SD)	Min	Max	Max	Max	Max						
social	1	resting story 1	6.76	(1.15)	3.29	9.99									
	2	comparison	6.81	(1.14)	3.29	9.65				–0.06	(0.65)		–0.26	(0.67)	***
	3	challenge	6.56	(1.12)	3.47	10.26									***
Cognitive	4	comparison	6.12	(1.22)	2.62	9.69				–0.75	(0.83)	***	0.60	(0.68)	***
	5	challenge	6.72	(1.11)	3.35	9.82									***
sensory	6	comparison	6.98	(1.15)	2.77	9.91				0.11	(0.77)	**	–0.32	(0.85)	***
	7	challenge	6.67	(1.21)	3.04	10.90									***
Emotional	8	comparison	7.04	(1.14)	2.74	10.15				0.16	(0.61)	***	0.10	(0.48)	***
	9	challenge	7.14	(1.12)	2.48	10.17									***
	10	resting story 2	6.98	(1.14)	3.49	9.84									
Pre-ejection Period:										Psychomotor Activity (comparison – rest)		Challenge Reactivity (challenge – comparison)		Overall Task Response (challenge – rest)	
Task-level PEP in ms										mean difference	SD	sig	mean difference	SD	sig
Domain	Block	Task Condition	Mean	(SD)	Min	Max	Max	Max	Max						
Social	1	resting story 1	78.41	(6.27)	57.60	93.90									
	2	comparison	78.39	(6.48)	56.78	93.35				–0.05	(1.95)		–0.02	(1.77)	
	3	challenge	78.48	(6.50)	55.40	94.18									
cognitive	4	comparison	78.16	(6.63)	54.85	93.90				–0.28	(2.33)	*	0.02	(1.57)	*
	5	challenge	78.23	(6.48)	57.05	94.45									
sensory	6	comparison	78.56	(6.67)	58.15	95.00				0.14	(2.28)		–0.10	(1.83)	
	7	challenge	78.43	(6.70)	51.55	96.65									
Emotional	8	comparison	79.20	(6.53)	53.75	95.00				0.73	(1.98)	***	–0.51	(1.79)	***
	9	challenge	78.71	(6.77)	52.65	95.55									*
	10	resting story 2	78.59	(6.46)	54.03	96.65									

Note: T-tests were conducted for each difference score a), b), and c) to determine if the values were significantly different than zero. Results of these t-tests are listed in the columns "sig"

100' > d

p < .001
10' > d
**
50' > d
*

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Table 2

Correlations among task RSA and PEP challenge reactivity (CR) and overall task responding (OTR) scores

Domain	Respiratory Sinus Arrhythmia (RSA)								Pre-ejection Period (PEP)							
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
1. Social CR	–								–							
2. Cognitive CR	-.09	–							-.01	–						
3. Sensory CR	.00	-.01	–						.12 *	-.09	–					
4. Emotional CR	.05	-.07	-.01	–					-.02	.03	.00	–				
5. Social OTR	.57 ***	-.12 *	.04	-.07	–				.58 ***	-.03	.03	-.12 *	–			
6. Cognitive OTR	.17 **	.25 ***	.08	-.07	.63 ***	–			.31 ***	.30 ***	-.04	-.15 **	.70 ***	–		
7. Sensory OTR	.15 **	-.05	.61 ***	-.03	.41 ***	.48 ***	–		.21 ***	.03	.47 ***	-.16 **	.43 ***	.55 ***	–	
8. Emotional OTR	.09	-.03	-.04	.34 ***	.25 ***	.29 ***	.31 ***	–	.16 *	.05	.01	.45 ***	.22 ***	.33 ***	.28 ***	–

Note. CR = Challenge Reactivity (challenge task – task-specific comparison); OTR = Overall Task Response (challenge task – resting stories average) = psychomotor activity + challenge reactivity. Values in **bold** indicate the intertask correlations for each measure by calculation. Values in *italics* indicate correlations between reactivity calculated by the two approaches.

* p < .05

** p < .01

*** p < .001