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# Respiratory Sinus Arrhythmia, Shyness, and Effortful Control in Preschool-Age Children

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## Abstract

Resting respiratory sinus arrhythmia (RSA) and shyness were examined as predictors of effortful control (EC) in a sample of 101 preschool-age children. Resting RSA was calculated from respiration and heart rate data collected during a neutral film; shyness was measured using parents', preschool teachers', and classroom observers' reports; and EC was measured using four laboratory tasks in addition to questionnaire measures. Principal components analysis was used to create composite measures of EC and shyness. The relation between RSA and EC was moderated by shyness, such that RSA was positively related to EC only for children high in shyness. This interaction suggests that emotional reactivity affects the degree to which RSA can be considered a correlate of EC. This study also draws attention to the need to consider the measurement context when assessing resting psychophysiology measures; shy individuals may not exhibit true baseline RSA responding in an unfamiliar laboratory setting.

### Keywords

Respiratory Sinus Arrhythmia (RSA); Shyness; Effortful Control; Executive Function; Vagal Tone

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Measures of autonomic nervous system function are valuable because they may provide additional information about internal states that are difficult to assess reliably using

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observation or self-report measures (Kagan, 1998), and can provide evidence for the underlying physiological mechanisms that support individual differences in temperament and adjustment (e.g., Beauchaine, Hong, & Marsh, 2008). The sympathetic nervous system (SNS) and parasympathetic nervous system (PNS) both exert influence on the heart, with opposing effects: the sympathetic nervous system in involved in metabolically costly fight/ flight responding, whereas the PNS slows heart rate, and has been conceptualized as a “brake” on heart rate (Porges, Doussard-Roosevelt, Portales, & Greenspan, 1996). Respiratory sinus arrhythmia (RSA)—referred to as vagal tone by some investigators because its effects are largely mediated by the vagus nerve (Porges, 2007)—is considered a measure of PNS influence on the heart. Resting RSA is a stable individual difference variable (Doussard-Roosevelt, Montgomery, & Porges, 2003; El-Sheikh, 2005) that has been studied extensively as a correlate of two aspects of temperament, effortful control (EC) and shyness/behavioral inhibition. To our knowledge, however, no researchers have attempted to understand how RSA is related to both of these aspects of temperament in the same individuals even though EC and shyness are believed to be largely orthogonal constructs (Rothbart, Ahadi, Hershey, & Fisher, 2001). In this study, we examine shyness as a moderator of the relations between RSA and EC.

## Effortful Control

Effortful control has been defined as “the efficiency of executive attention—including the ability to inhibit a dominant response and/or to activate a subdominant response, to plan, and to detect errors” (Rothbart & Bates, 2006, p. 129). There are conceptual similarities between RSA and both EC. High RSA is thought to index emotion regulation (e.g., Beauchaine, Gatzke-Kopp, & Mead, 2007; Fabes & Eisenberg, 1997; Gyurak & Ayduk, 2008). Similarly, EC is believed to underlie effective emotion regulation (Eisenberg, Hofer, & Vaughan, 2007; Rothbart & Bates, 2006), and would therefore be expected to relate positively to RSA. Neuroscience research also supports a link between RSA and EC, as the anterior cingulate cortex is believed to provide the neural basis for EC (Fan, Fossella, Sommer, Wu, & Posner, 2003; Posner & Rothbart, 1998), and activity in the anterior cingulate cortex also is associated with PNS function (Gianaros, Van Der Veen, & Jennings, 2004; Matthews, Paulus, Simmons, Nelesen, & Dimsdale, 2004).

Positive relations between attentional control—an important component of EC—and resting RSA have sometimes been documented in the literature. For fourth and fifth graders and for adults, performance on a continuous performance task (a measure of attentional control) was found to be positively associated with resting RSA (Hansen, Johnsen, & Thayer, 2003; Suess, Porges, & Plude, 1994). In a sample of children and adolescents ranging from eight to 17 years old, resting RSA was positively related to parents’ reports of EC (Chapman, Woltering, & Lewis, 2010).

Studies also show that resting RSA is positively related to performance on complex cognitive tasks involving executive functioning (EF)—a capacity that has considerable conceptual overlap with EC (Zhou, Chen, & Main, 2012)—across the lifespan. In a study of 3.5-year-old children, resting RSA was positively related to performance on two EC/EF tasks (Marcovitch et al., 2010), and in school-age children resting RSA was found to be positively related to EF and processing speed, but unrelated to more general measures of cognitive ability (Staton, El-Sheikh, & Buckhalt, 2009). Similarly, resting RSA was negatively related to adults' processing time during a Stroop task (Mathewson et al., 2010). Finally, RSA was found to correlate with a composite measure of EC/EF in a sample consisting mostly of boys, half of whom had emotional or behavioral disorders (Mezzacappa, Kindlon, Saul, & Earls, 1998).

In contrast to this evidence, some researchers have failed to document significant relations between baseline RSA and EC/EF. For example, performance on two behavioral EC measures was unrelated to resting RSA in sample of low-income preschoolers enrolled in Head Start (Blair & Peters, 2003). Null relations between resting RSA and a cognitive signal detection task also were observed for college students (Duschek, Muckenthaler, Werner, & Reyes del Paso, 2009). Nonetheless, the literature suggests that resting RSA is positively related to EC in school-age children and adults, although few investigators have examined these relations in preschool-age children.

## Shyness and Behavioral Inhibition

Coplan and Rubin (2010, p. 9) defined shyness as "(Temperamental) wariness in the face of social novelty or self-conscious behavior in situations of perceived social evaluation." Behavioral inhibition, in contrast, is a dimension of temperament characterized by high emotional reactivity to the unfamiliar (Snidman, Kagan, Riordan, & Shannon, 1995). According to Fox and colleagues (Fox, Henderson, Rubin, Calkins, & Schmidt, 2001, p. 2), "Reticence [i.e., shyness] is conceptually related to behavioral inhibition based on the common underlying motivation to avoid novelty due to the negative affect elicited by novel stimuli." Behavioral inhibition is characterized by emotional reactivity to unfamiliar situations in general, whereas shyness is specific to social situations and may also involve fear of being evaluated in addition to emotional reactivity to the unfamiliar (Xu, Farver, Yu, & Zhang, 2009). As might be expected based on the overlap between these constructs, shyness and behavioral inhibition have been found to be positively correlated (Xu et al., 2009). Furthermore, shyness and behavioral inhibition have both been reported to predict the development of anxiety problems (e.g., Prior, Smart, Sanson, & Oberklaid, 2000).

High resting RSA is believed to index the ability to engage with the environment (Porges, 2007), as well as flexibility in responding (Thayer & Lane, 2000). Because shyness and behavioral inhibition are characterized as relatively inflexible emotional responses to novelty, these constructs would be expected to relate negatively to RSA. In addition, there appears to be a shared neural basis for shyness and RSA, with activity in the insula associated with both shyness (Beaton, Schmidt, Schulkin, & Hall, 2010) and PNS function (Gianaros et al., 2004; Lane et al., 2009).

The standard deviation of heart period, a measure of heart rate variability that is strongly correlated with RSA (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996), has been found to relate negatively to behavioral inhibition in some studies. For example, children classified as behaviorally inhibited at 21 months of age had a smaller heart period *SD* across a battery of tasks at age 4 relative to children who were not inhibited (Kagan, Reznick, Clarke, Snidman, & Garcia-Coll, 1984). Some investigators also have observed a negative relation between children's behavioral inhibition and RSA (Fox, 1989; Putnam, 2000; K. H. Rubin, Hastings, Stewart, Henderson, & Chen, 1997) or between parental ratings of shyness and RSA (Doussard-Roosevelt et al., 2003; Kagan, Reznick, Snidman, Gibbons, & Johnson, 1988). In addition, RSA has been found to relate negatively to infants' social fear (Stifter & Jain, 1996) and to preschoolers' social reticence (Henderson, Marshall, Fox, & Rubin, 2004). Although some researchers have failed to find significant relations between RSA and behavioral inhibition (Burgess, Marshall, Rubin, & Fox, 2003; Marshall & Stevenson-Hinde, 1998) or shyness (Dietrich et al., 2009; Schmidt, Fox, Schulkin, & Gold, 1999), overall the evidence suggests that baseline RSA is negatively related to these constructs.

## The Present Investigation

As discussed, a number of investigators have attempted to examine the direct relations between baseline RSA and temperamental characteristics such as EC and shyness. To our knowledge, however, moderators of the relation between RSA and EC have not been examined. In this study, we attempt to predict EC from the interaction between baseline RSA and shyness. RSA was expected to relate more strongly to EC under conditions that require effective emotional self-regulation (cf., Krypotos, Jahfari, van Ast, Kindt, & Forstmann, 2011), and the experimental situation was expected to be more arousing for children high in shyness than for children low in shyness. Thus, we hypothesized that RSA would be more strongly related to EC for those children high in shyness because shy children with greater attentional resources, compared to shy children with low attentional regulation, should be better able to regulate their emotional arousal in an unfamiliar setting.

## Method

The study consisted of three components: (1) a laboratory visit in which heart rate and respiration were recorded during a baseline film, and in which children completed three tasks assessing EC (2) a second, shorter laboratory session in which children completed a continuous performance task (another behavioral measure of EC); and (3) questionnaires measures of children's shyness and EC that were completed by parents, preschool teachers, and classroom observers.

### Participants

Participants were 106 children (42 girls) attending any of the three research preschools at a southwestern university campus who gave assent for physiological recording. All subsequent analyses include data for the 101 children (40 girls) who had complete physiological data for a baseline film. Physiological data were missing for five children due to problems with the recording of respiration (e.g., improper placement of the respiration bellows). Age ranged from 3.31 to 5.88 years ($M$ = 4.49; $SD$ = 0.63).

Parents of eighty-three children in the current study returned questionnaires that included demographic information. Education was reported on a 7-point scale (1 = did not graduate high school; 7 = Ph.D. or professional degree). The median level of parental education averaged across both parents was 4-year college graduate. Annual family income was also reported on a seven-point scale (1 = < $10,000; 7 = more than $100,000). Median family income was $75,000-$100,000. Six percent of children were from single-parent families. Children's racial composition, as reported by parents, was as follows: 73% Caucasian; 2% African American; 9% Asian; 4% Native American; 12% other/multiracial. Eighteen percent of parents reported that their children were Mexican American/Hispanic in ethnicity.

## Laboratory Procedure

Prior to the laboratory session, we employed several methods to familiarize children with the experimenters and the physiological hook-up procedures. Experimenters spent some time playing with children in their classroom so that the children would be somewhat familiar with them. In addition, experimenters demonstrated the physiological hook-up procedure in the classroom during group instructional time and allowed children to try putting on the respiration bellows and the electrodes. To make the electrodes more appealing, we placed animal stickers on them.

Each laboratory session was administered by one experimenter and one camera person, both of whom were trained undergraduate or graduate research assistants. There were a total of 24 experimenters/camera people (14 female, 10 male) across three semesters of data collection.[1] Undergraduate research assistants were supervised by a graduate student or faculty member to ensure quality, and laboratory sessions were video recorded for later behavioral coding. Experimenters brought children from their preschool classroom into the laboratory testing room, which was located close to the classrooms in each preschool. After obtaining child assent, experimenters attached three electrodes in an inverted triangle configuration to the child's chest and abdomen and placed a respiration bellows around the child's torso. Heart rate and respiration data were collected while children watched a relaxing video. Children participated in three tasks (introduced as games) to assess EC with the experimenter. At the end of the session, children received a small toy to thank them for participating.

**Physiological Baseline—**Children were seated in front of a laptop computer and instructed to watch a meditation video showing dolphins swimming while relaxing music played. The experimenter told children that he or she had to do computer work and would not be able to talk to the child while the movie was playing. If children stopped paying attention to the movie, fidgeted excessively, or attempted to talk to the experimenter or camera person, the experimenter redirected them to continue watching the film. The dolphin film lasted two minutes and 38 seconds.

**Laboratory Measures of Effortful Control—**We used four laboratory tasks to measure EC. Two of these tasks, bird and dragon and gift wrap, were adapted from Kochanska's (Kochanska & Knaack, 2003; Murray & Kochanska, 2002) battery of EC tasks and are

[1]We dummy coded four variables: (1) the sex of the experimenter; (2) the sex of the camera person; (3) whether the sex of experimenter matched the sex of the child, and (4) whether the sex of the camera person matched the sex of the child. None of these were significantly correlated with any other study variables, and controlling for these dummy codes did not substantively alter the results of our multiple regression analyses; all significant predictors (at $p < .05$) remained significant.

commonly combined to form an index of self-regulation. A third task, knock tap, has been used to measure executive functioning (Luria, 1966); variants of this task have been used as a measure of EC/EF in other studies of preschool age children (Blair, 2003; Diamond & Taylor, 1996). Each of these tasks was coded by two trained undergraduate research assistants who were not involved in collecting data for this study. A primary coder viewed all tapes and a reliability coder independently viewed at least 25% of the tapes. To assess reliability, the intraclass correlation (ICC) between the main and reliability coders was computed for each measure. Coders also rated task quality as usable or unusable; although rare, data for tasks that were scored as unusable were set to missing. A fourth laboratory measure, a computerized continuous performance task (CPT; similar to that used by Rosvold, Mirsky, Sarason, Bransome, & Beck, 1956), was also used to measure EC; this task was performed in a separate laboratory session. Similar or identical CPT tasks have been used in other studies as a measure of attentional control (e.g., NICHD Early Child Care Research Network, 2003; Sulik et al., 2010).

**Bird and dragon:** For the bird and dragon game (Murray & Kochanska, 2002), the experimenter had two puppets, which were introduced as the nice bird and mean dragon. Children were instructed to “Do what the nice bird says” but “Don’t do what the mean dragon says.” After completing practice trials to ensure that the child understood the game, the experimenter used the puppets to issue a series of commands (6 bird commands and 10 dragon commands). Each trial was scored as correct (3), partially correct (2), or incorrect (1). An activation control composite and an inhibitory control composite were calculated as the average score on the correct bird and dragon trials, respectively. The product of these two scores was used as a measure of EC. This scoring was done to prevent children who never performed an action and children who responded indiscriminately to all commands from getting a high score. As a result of this scoring procedure, children would need to respond correctly to both types of trials to receive a high score; children who either responded to both types of trials or did not respond to either type of trial would receive a low score. The average score for the bird trials was 2.71 (*SD* = .66), the average score for the dragon trials was 2.66 (*SD* = .81; ICCs = 1.0 and .99, respectively.

**Knock tap:** For the knock tap game (Luria, 1966), children first completed eight imitation trials. During the imitation trials, when the experimenter knocked on the table (i.e., closed fist), the child was asked to knock on the table. When the experimenter tapped on the table (i.e., open palm), the child was asked to tap on the table. Following the imitation trials, the test trials were conducted in which children played the game a “Tricky way.” During the test trials, children were asked to tap on the table when the experimenter knocked, and to knock on the table when the experimenter tapped. The experimenter performed 24 test trials, which were scored as correct (1) or incorrect (0). Trials in which a child responded at the same time or prior to the experimenter's action were scored as incorrect unless the child corrected his or her answer. Some children became bored with the task and stopped playing; these trials were considered missing, rather than incorrect. The proportion of correct responses during the test trials was computed as a measure of EC (ICC = .98).

**Gift wrap:** In this task, experimenters told children that they had a surprise for them, and children were asked to look straight ahead at the wall in front of them so that the experimenter could wrap their gift. The experimenter reminded the child not to peek and noisily wrapped a gift behind the child for one minute. At the end of this period, the experimenter gave the gift to the child. Children's peeking behavior was coded as follows: 5 = Child does not peek; 4 = Child peeks, but does not turn body and does not turn head over shoulder; 3 = Child peeks, but does not turn body; 2 = Child turns body while peeking in last 10 seconds, or child turns body while peeking for three seconds or less; 1 = Child turns body while peeking for more than three seconds (ICC = .81).

**Continuous performance task:** In a separate laboratory session, children's EC was assessed using a computerized continuous performance task (CPT; Rosvold et al., 1956). Children were seated in front of a laptop computer with all keys covered except for the space bar. Children were instructed to press the space bar when they saw a fish, but to refrain from pressing the spacebar when other pictures were displayed (e.g., a beach ball, an umbrella). Each picture was displayed for 500 ms and there was 1500 ms between each stimulus presentation. Fish were displayed on 32 (20%) of the 140 trials. Signal detection theory (Wickens, 2002) was used to score the results as follows: each trial in which the fish was presented was scored as a hit (1) or a miss (0), whereas each trial in which the fish was not presented was scored as a correct rejection (1) or a false alarm (0). The proportion of hits for the fish trails and the proportion of correct rejections for the non-fish trials were computed, and these probabilities were converted into *z*-scores. By computing the difference between these two *z*-scores, these transformations allow the means of the two distributions to be compared on a standard deviation metric. This difference score, known as detectability, indexes how well children were able to behaviorally discriminate between fish and non-fish trials. Detectability was used in the analyses as an index of EC.

## Physiological Data

Heart rate and respiration were measured during the dolphin film and during bird and dragon, knock tap, and gift wrap tasks. Physiological measures were recorded using James Long Company (Caroga Lake, New York) equipment and the data acquisition program SnapMaster for Windows. The physiological measures were digitized at 512 samples per second with a 31-channel A/D converter operating at a resolution of 12 bits and having an input range of −2.5 to +2.5 V. All psychophysiological channels were amplified by individual SA Instrumentation Bioamplifiers. The electrocardiogram was recorded with an amplification rate of 250, a high-pass filter of 0.1 Hz, and a low pass filter of 1000 Hz. The amplification of the respiration signal was adjusted as needed by the experimenters and was recorded with a low pass filter of 10 Hz. Interbeat interval (IBI) data were scored using James Long Company software and then visually inspected for errors. Missing IBI data, although rare, were prorated based on the surrounding IBIs. RSA was calculated using the peak-to-trough method (Grossman, Karemaker, & Wieling, 1991) with James Long Company (2008) software.

One outlier that was more than 3 *SD* above the mean for baseline RSA was recoded so that the score was 3 *SD* from the mean (Tabachnik & Fidell, 2006); this procedure reduces the influence that outliers have on the analysis without discarding them completely. This change did not substantially alter the results of any subsequent analysis. Mean RSA after recoding the outlier was 0.082 s (*SD* = 0.047 s). When the peak-to-trough measure of RSA was converted into the more commonly reported metric of $\ln(ms^2)$, the mean was 6.43 (*SD* = 1.13).

## Children's Behavior Questionnaire

The Children's Behavior Questionnaire (CBQ; Rothbart et al., 2001) is a commonly used measure of temperament that includes scales that assess attention focusing, inhibitory control, and shyness. Consistency for the CBQ scales is more modest across reporters, however, which may partially reflect situational differences that influence the behavioral expression of temperament. For example, a child may act differently at home and at school so parent and teacher reports would be expected to differ to the extent that parents and teachers observe objectively different behavior (Kagan & Fox, 2006). For this reason, it is often desirable to obtain multiple reporters for a more complete view of children's EC. In this study, we collected CBQ data from three different reporters: classroom observers, parents, and preschool teachers.

Over the course of one semester, trained undergraduate research assistants (who were not involved in data collection for the laboratory portions of the study) observed children in their classroom while doing short observational scans coding for aggression and play behaviors (blinded for review). These observers also completed questionnaires about children's temperament, as described below. Between two and eight classroom observers rated each child. The questionnaires were intended to be global assessments of the children's temperament, and were completed at the end of the semester, after the observers had spent an extensive amount of time observing these children in their classrooms. Observers reported their confidence in rating each child on a 7-point Likert scale. For children with a confidence rating of less than 4, observer data were discarded; this resulted in dropping approximately 5% of the observer questionnaire data. Because the number of observer ratings retained for each child ranged from one to eight (*M* = 3.39; *SD* = 1.45), scores on the individual items were averaged across observers, and these averages were used to create scale scores and to calculate reliability numbers for these scales.

Teachers or teachers' aides (for 100 children), parents (*n* = 83; 13 fathers), and observers (at least one observer completed questionnaires for each of the 101 children) filled out the short form of the CBQ, a well-validated and widely used measure of temperament developed for children age three to seven (Putnam & Rothbart, 2006; Rothbart et al., 2001). The scales for inhibitory control (e.g., "Can wait before entering into new activities if s/he is asked to"), attention focusing (e.g., "When drawing or coloring in a book, shows strong concentration"), and shyness (e.g., "Seems to be at ease with almost any person") each consisted of six items. Cronbach's $\alpha$ reliability coefficients for parent, teacher, and observer report data were acceptable for inhibitory control ($\alpha$s = .70, 80, and .89), attention focusing ($\alpha$s = .63, .85, and .85), and shyness ($\alpha$s = .84, .84, and .89).[2] Within each reporter, attention focusing and inhibitory control were substantially correlated, $r(84) = .35$ for parents, $r(100) = .70$ for teachers, and *r*(101) = .81 for observers); these scales were averaged to create a composite questionnaire measure of EC for each reporter.

# Results

## Missing Data

Baseline RSA was required for inclusion in the analysis sample. The proportions of participants with missing data for other study variables were as follows: Parent EC and shyness = .17; Teacher EC and shyness = .01; Bird and Dragon = .03; Knock Tap = .05; Gift Wrap = .01; CPT = .12. There were no missing data for observer-rated EC and shyness. Parent data were sometimes missing because not all parents completed and returned questionnaires. In addition, there was a larger proportion of missing data for the CPT relative to the other tasks because consent for the second laboratory session involving the CPT was obtained separately, and not all parents returned the consent form.

Multiple imputation was used as a missing data treatment. Multiple imputation generates multiple copies of a data set and fills in the missing values with scores that are adjusted with random error. These data sets are then analyzed separately and the results across analyses are pooled (D. B. Rubin, 1987). This procedure produces unbiased estimates for data that are missing completely at random or missing at random (Schafer & Graham, 2002). Even when this assumption is not met, multiple imputation produces less biased estimates than traditional missing data treatments such as listwise deletion while at the same time maintaining relatively high statistical power (Enders, 2010). Ten data sets were imputed using SAS 9.3, and autocorrelation plots were used to verify the independence of imputed data sets (Enders, 2010). All results reported in this manuscript reflect the pooled estimates across imputations.

## Correlations and Descriptive Statistics

Correlations among all study variables are presented in Table 1. All EC variables with the exception of observers' reports were significantly intercorrelated, with *r*s ranging from .26 to .51. Parents', teachers', and observers' reports of shyness were also significantly intercorrelated, with *r*s ranging from .21 to .36. Age, but not sex, was positively correlated with the laboratory measures of EC, whereas sex, but not age, was correlated with reports of EC (girls were higher). RSA was positively correlated with heart period and respiration period, *r*s = .72 and .37. None of these physiological variables was correlated with any other study variables with the exception of the correlation between respiration period and gift wrap, *r* = .20. None of the measures of EC was significantly correlated with measures of shyness except for a negative relation between gift wrap and observers' reports of shyness, *r* = −.25.

[2]There was a variable number of classroom observers who filled out the CBQ on each child in this study. To ensure that averaging the responses to each item across observers prior to computing the reliability of the scale did not obscure problems in reliability, we randomly selected one observer for each child and calculated the reliability of the CBQ scales in this subset of observers. When only one observer was selected per child, Cronbach's α was .84 for inhibitory control, .81 for attention focusing, and .88 for shyness.

## Data Reduction

Principal components analysis (PCA), an analytic technique that produces weighted component scores by extracting the common variance among a set of variables, was used as a data reduction technique (Tabachnik & Fidell, 2006). This procedure reduces a set of variables into a smaller number of composites that can be used in subsequent analyses. EC and shyness were analyzed in separate principal components analyses using SAS 9.3. Horn's (1965) parallel analysis criterion—regarded as one of the most accurate methods for identifying the correct number of components for extraction (Hayton, Allen, & Scarpello, 2004; Lance, Butts, & Michels, 2006)— indicated that only the first component should be extracted for EC and for shyness. For observers' reports of EC, the communality was only .21, whereas the communalities for all other EC measures in this analysis ranged from .41 to .52. Consequently, observers' reports of EC were dropped from the principal components analysis for EC. Communalities and eigenvalues of the final PCA analyses are presented in Table 2. The EC and shyness composites were not significantly correlated with each other nor related to age, sex, or the physiological variables with the exception of significant correlations for the EC composite with age, $r = .47$, $p < .001$, and RSA, $r = .23$, $p < .05$. The component scores for EC and shyness were used in subsequent analyses.

## Hierarchical Regression Analyses

Hierarchical multiple regression analyses were run with four sets of predictors entered sequentially: (1) age and sex; (2) the main effects of RSA and shyness; (3) the RSA × Shyness interaction; and (4) two- and three-way interactions with sex. For each set, $r^2$ is reported as a measure of effect size. Because multiple imputation was used in this study, the $D_m$ statistic for multivariate inferences (Li, Raghunathan, & Rubin, 1991) was used to determine whether the addition of each set of predictors significantly increased the model $r^2$. This test approximates an *F* distribution with numerator degrees of freedom equal to the number of predictors in the set, and denominator degrees of freedom based on the fraction of missing information and the number of imputations (for formulas, refer to SAS Institute, Inc., 2008). Controlling for the preschool that children attended did not substantively change the results of any of the regression analyses; thus, these dummy codes were dropped from the analyses. One child had an extremely low score on the EC composite ($z = -3.41$) and was consequently very influential in the initial runs of the regression analyses. Because of concerns that this child may have had developmental delays, this child was excluded from the analyses reported below ($N = 100$ after excluding this child); this procedure did not change the substantive results of our analyses.

Age and sex were both significant predictors of EC in the first set, *b*s = .73 and .41, *t*s = 5.46 and 2.41, *p*s < .001 and < .05 (see Table 3); older children and girls were higher in EC. In the second set, the addition of the main effects of RSA and shyness did not significantly improve prediction, $D_m = 2.51$, $p < .10$. In this analysis, RSA was a significant predictor of EC, $b = 3.74$, $t = 2.01$, $p < .05$. When the RSA × Shyness interaction was entered into the model in the third set, it significantly improved prediction, $D_m = 5.32$, $p < .05$, and the interaction term was significant[3], $b = 4.45$, $t = 2.35$, $p < .05$. The inclusion of the interaction term increased the $r^2$ by .05, from .29 to .34. Adding interactions with sex in the fourth set did not improve prediction, $D_m = 0.40$, *ns*, and none of the two- or three-way interactions with sex was significant. Aiken and West's (1991) procedure was used to probe the significant RSA × Shyness interaction. The simple effect of RSA on EC was significant at +1 *SD* above the mean on shyness, $b = 7.49$, $t = 3.07$, $p < .01$ (see Figure 1). There was no relation between RSA and EC at mean shyness or at −1 *SD* below the mean on shyness, *b*s = 3.04 and −1.43, *t*s = 1.64 and −0.50, *ns*.

RSA is considered a relatively pure measure of PNS activity, but heart period is also influenced by the SNS. To determine whether these moderation results were specific to PNS activity, we also examined the Heart Period × Shyness interaction as a predictor of EC. This interaction was significant, $b = 3.08$, $t = 2.04$, $p < .05$. Consistent with the high correlation between heart period and RSA in our sample ($r = .72$), examining the simple slopes revealed that this interaction was similar to the RSA × Shyness interaction: At high levels of shyness (+1 *SD*), heart period was marginally positively related to EC, $b = 4.02$, $t = 1.89$, $p = .06$; at mean and low (−1 *SD*) levels of shyness, heart period was unrelated to EC, *b*s = 0.92 and −2.16, *t*s = 0.65 and −1.07, *ns*. We also conducted additional analyses in which we partialed RSA out from heart period, and examined the residual (i.e., the variance in heart period that is statistically independent of RSA) in relation to EC. Neither the main effect of this variable nor its interaction with shyness predicted EC.

## Discussion

The question addressed by this study was whether RSA assessed in a laboratory context would differentially predict EC for children high and low in shyness. A particular strength of this study was the multi-method approach to the measurement of temperament (Eid & Diener, 2005): EC was assessed with behavioral measures as well as questionnaires, and questionnaire measures of temperament were administered to multiple reporters to obtain a more complete view of children's shyness and EC.

As predicted, the relation between baseline RSA and EC was moderated by shyness. Baseline RSA predicted EC only for children high in shyness. Given the evidence that stress and worry apparently contribute to reductions in RSA (Brosschot, Van Dijk, & Thayer, 2007; Pieper, Brosschot, Van Der Leeden, & Thayer, 2007), low RSA is likely indicative of low EC for shy children because these children are unable to regulate their emotional reactivity to the unfamiliar. RSA was unrelated to EC for children average or low in shyness, perhaps because these children do not need to regulate their emotional reactivity in the context of the unfamiliar laboratory setting with two adults that they do not know well.

These results may indicate that consideration of the measurement context, as well as individual characteristics of the participants, are important when attempting to relate RSA to psychological variables. In particular, baseline RSA is likely to be more strongly related to variables that support emotion-related regulation (e.g., EC) for participants who are prone to

[3]Consistent with evidence that the peak-to-trough method of computing RSA is confounded by respiration rate (Lewis, Furman, McCool, & Porges, 2012), we found a substantial correlation between respiration period and RSA, $r(98) = .37$, $p < .001$. Consequently, we regressed RSA on respiration period and saved the residual from this analysis for use as an alternative measure of RSA that is statistically adjusted for respiration rate. Hierarchical regression analyses using this term (which was highly correlated with the unadjusted measure of RSA, $r = .94$) were not substantively different from the unadjusted measure of RSA, indicating that our results cannot be attributed to differences in respiration period across subjects.

be emotionally reactive in a given measurement context (e.g., shy or behaviorally inhibited children or anxiety disordered patients in a novel testing situation, especially those with generalized anxiety disorder or social phobia). Because stress has been demonstrated to affect RSA (Pieper et al., 2007), individuals who find the measurement context to be a source of worry will likely demonstrate attenuated RSA to the degree that they experience anxiety in that context (Brosschot et al., 2007) and are unable to use attentional resources to control their emotional reactivity (White, McDermott, Degnan, Henderson, & Fox, 2011).

Psychophysiological variables such as RSA are believed to index individual differences in temperamental reactivity and self-regulation (Beauchaine et al., 2007). Yet reliable differences in temperament are contingent on appropriate eliciting conditions (Rothbart & Bates, 2006). Thus, we might expect psychophysiological variables related to emotional arousal and corresponding aspects of temperament to show the closest correspondence when they are measured in together in situations that reliably elicit the temperamental dimension of interest. For shyness or behavioral inhibition, we would expect this to occur when exposed to unfamiliar situations or people (e.g., Kagan et al., 1984). Consequently, a possibility that merits further exploration is that the measure of resting RSA used in this study (and similar measures of RSA used in many other studies) did not constitute a true baseline measure of RSA. Although reasonable efforts were made to make the laboratory setting less threatening for participants, children who participated in this study were brought into an unfamiliar laboratory setting with two adults (the experimenter and camera person) whom they did not know very well and were subjected to physiological hookup, which involved the placement of electrodes on their chest and abdomen. It is likely that children who are shy or behaviorally inhibited, being emotionally reactive to unfamiliar persons and situations, would exhibit lower RSA in the laboratory context relative to RSA measured in a more familiar context (e.g., at home) or in the presence of familiar adults (e.g., parents). Although the finding will need to be replicated, the interaction between shyness and baseline RSA as a predictor of EC found in this study may help organize the body of findings documenting a relation between baseline RSA and two aspects of temperament, EC and behavioral inhibition/shyness. Moreover, our results highlight the importance of simultaneously considering the role of RSA as a measure of emotional reactivity (in this case, shyness in an unfamiliar laboratory setting) and self-regulation; investigators should not assume that RSA is equally related to constructs such as EC/EF for all children, but should instead consider individual differences that moderate these relations.

Although this study focused primarily on relations between PNS activity and temperament, future work should also consider SNS activity as well. Although these two branches of the autonomic nervous system have opposing effects, their activity can become decoupled (Berntson, Cacioppo, Quigley, & Fabro, 1994). Studies have begun to investigate the joint contributions of PNS and SNS activity to mental health (e.g., Beauchaine et al., 2008; Bubier, Drabick, & Breiner, 2009; El-Sheikh et al., 2009), and an important direction for future research will be to examine activity in the SNS and PNS simultaneously in studies of temperament and personality. In addition, it is also clear that autonomic reactivity—changes in autonomic function in response to task demands—may also provide information about self-regulatory ability (Gentzler, Santucci, Kovacs, & Fox, 2009; Marcovitch et al., 2010).

Consequently, future studies should also examine autonomic reactivity in addition to resting measures.

It is unclear whether the findings from this study would generalize to other ages. The children in this study ranged from age 3.5 to 5; this age range was chosen as this is a period during which EC develops rapidly, which was supported by the substantial correlation between laboratory measures of EC and age in this study. Beauchaine (2001) argued that the interpretation of RSA changes from infancy to later childhood. The evidence, although somewhat equivocal, does support this position. For example, some studies find that positive or negative emotional reactivity are positively related to RSA in infancy (e.g., Stifter & Fox, 1990; Stifter & Jain, 1996), although studies showing relations between RSA and emotional reactivity (with the exception of shyness or behavioral inhibition) are not common in older children.

Prior to age 2, children generally lack substantial self-regulatory ability (Kochanska, Murray, & Harlan, 2000). Therefore, any relation between RSA and EC might not expected for toddlers, although the relations between shyness and RSA may be more pronounced for children in this age range because of low self-regulatory ability and a fear of strange adults (Sroufe, 1977). Conversely, school-age children—even those high in shyness—may not find a strange laboratory situation very threatening. Therefore, additional research is needed to determine whether the relations observed in this study are also present in younger and older children. Moreover, given the relatively high socioeconomic status of the children and the fact that they were predominantly non-Hispanic Caucasians, it is unclear if the findings generalize to lower socioeconomic and minority populations. In addition, we do not know the extent to which additional accommodations to reduce emotional reactivity in shy children, such as the presence of a caregiver, might attenuate or eliminate the interaction effect observed in this study.

Despite these limitations, this study addresses important questions about the interpretation of RSA. Researchers have recognized that psychophysiological measures such as RSA do not have a one-to-one correspondence with psychological constructs (Berntson, Cacioppo, & Grossman, 2007). According to Cacioppo and Tassinary (1990), specification of the conditions under which a psychological variable (in this case, EC) is related to a psychophysiological variable such as RSA is needed for accurate inference. RSA is commonly used as an index of emotion regulation, but this study indicates that RSA is related to EC only for some children (i.e., those high in shyness). Therefore, it may be inappropriate to interpret RSA as an index of self-regulation for all children.

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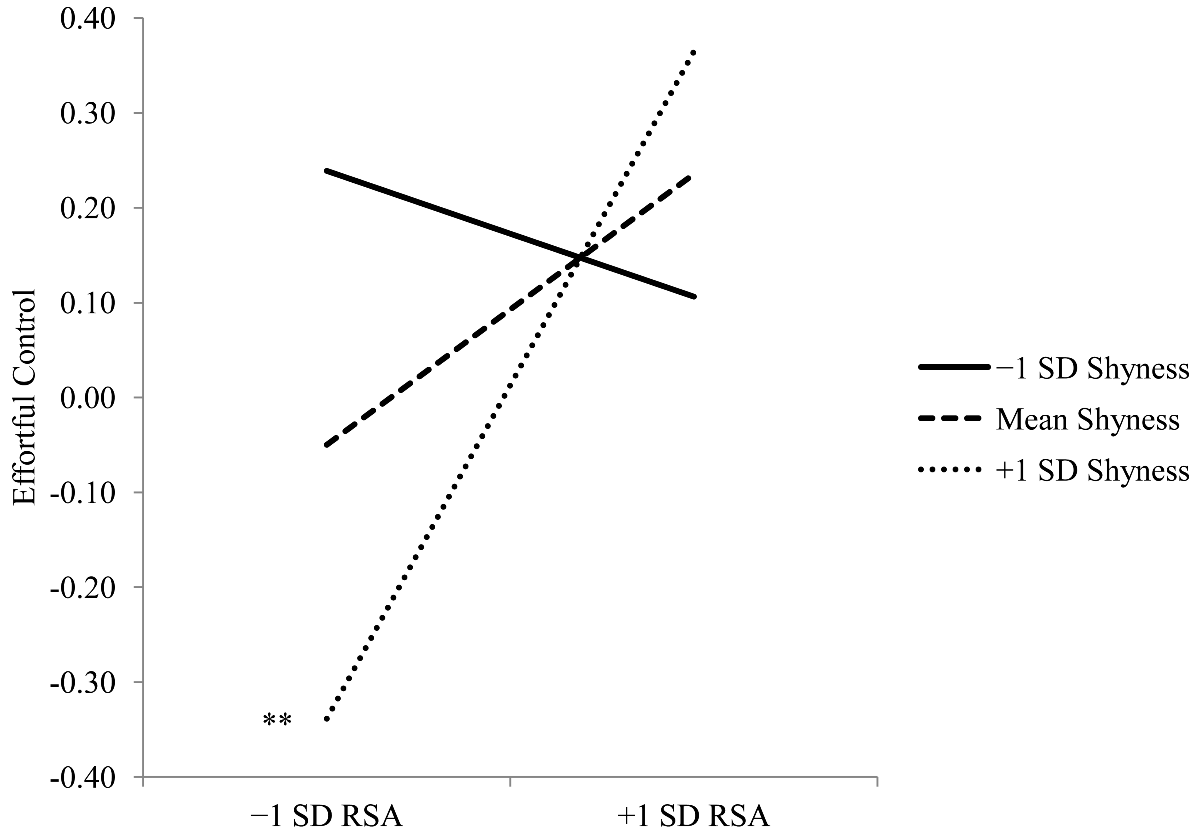
## Highlights

- Preschool-aged sample
- Multiple methods used to measure effortful control (EC) and shyness
- Tested the interaction of respiratory sinus arrhythmia X shyness as predictor of EC
- Respiratory sinus arrhythmia related to EC only for children high in shyness
- Importance of context for resting physiological recordings is emphasized




*Note*. ** $p < .01$.

**Figure 1.**
Simple Effect of Baseline RSA on Effortful Control at Varying Levels of Shyness

## Table 1

Descriptive Statistics and Correlations among Study Variables

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Heart Period | - | **.72** | .03 | *.19* | −.13 | −.00 | .05 | .12 | .02 | −.02 | .03 | −.03 | −.13 | −.11 | −.07 |
| 2 | Baseline RSA | | - | **.37** | .14 | −.12 | .02 | .05 | .17 | .09 | .13 | .06 | −.01 | −.12 | −.12 | .06 |
| 3 | Respiration Period | | | - | .04 | .12 | .10 | −.06 | **.20** | *.21* | −.09 | −.03 | .07 | .01 | .00 | −.14 |
| 4 | Age | | | | - | −.15 | **.33** | **.44** | **.31** | **.40** | .14 | .13 | −.06 | .04 | −.06 | **−.29** |
| 5 | Sex | | | | | - | .03 | −.08 | .05 | .15 | **.22** | **.30** | **.32** | .08 | −.11 | .02 |
| 6 | Bird and Dragon | | | | | | - | **.34** | **.44** | **.51** | **.26** | **.30** | .15 | −.17 | −.09 | −.09 |
| 7 | Knock Tap | | | | | | | - | **.42** | **.32** | **.37** | **.34** | **.21** | .16 | −.11 | −.11 |
| 8 | Gift Wrap | | | | | | | | - | **.42** | **.37** | **.25** | .10 | .00 | *−.18* | **−.25** |
| 9 | CPT Detectability | | | | | | | | | - | **.30** | **.40** | **.23** | −.09 | −.11 | *−.19* |
| 10 | Parent EC | | | | | | | | | | - | **.42** | *.19* | .09 | −.03 | .08 |
| 11 | Teacher EC | | | | | | | | | | | - | **.43** | −.08 | −.06 | .14 |
| 12 | Observer EC | | | | | | | | | | | | - | −.01 | .07 | .10 |
| 13 | Parent Shyness | | | | | | | | | | | | | - | **.36** | **.21** |
| 14 | Teacher Shyness | | | | | | | | | | | | | | - | **.33** |
| 15 | Observer Shyness | | | | | | | | | | | | | | | - |
| | Mean | 0.61 | 0.08 | 2.81 | 4.49 | - | 7.15 | 0.66 | 4.50 | 2.88 | 5.11 | 5.29 | 4.88 | 3.63 | 3.01 | 3.28 |
| | *SD* | 0.06 | 0.05 | 0.50 | 0.63 | - | 2.88 | 0.28 | 0.97 | 0.97 | 0.71 | 1.10 | 0.64 | 1.25 | 1.22 | 0.79 |

*Note*. $p < .05$ is bold; $p < .10$ is italic. Sex is coded as follows: 0 = male, 1 = female.

**Table 2**

Principal Components Analyses: Communalities and First Eigenvalue

| | Communalities | |
|---|---|---|
| **Variable** | **Effortful Control** | **Shyness** |
| Bird & Dragon | 0.48 | |
| Knock Tap | 0.51 | |
| Gift Wrap | 0.45 | |
| CPT Detectability | 0.53 | |
| Parent-Report EC | 0.42 | |
| Teacher-Report EC | 0.42 | |
| Parent-Report Shyness | | 0.51 |
| Teacher-Report Shyness | | 0.63 |
| Observer-Report Shyness | | 0.46 |
| First Eigenvalue | 2.82 | 1.60 |

## Table 3

Results of Hierarchical Multiple Regression Analyses Predicting Effortful Control from RSA and Shyness

| | Demographics | | | Main Effects | | | Interaction | | |
|---|---|---|---|---|---|---|---|---|---|
| | ***b*** | ***t*** | | ***b*** | ***t*** | | ***b*** | ***t*** | |
| Intercept | −0.13 | | | −0.14 | | | −0.12 | | |
| Age | 0.73 | 5.46 | *** | 0.67 | 5.04 | *** | 0.70 | 5.33 | *** |
| Female | 0.41 | 2.41 | * | 0.44 | 2.58 | * | 0.43 | 2.60 | ** |
| RSA | | | | 3.74 | 2.01 | * | 3.03 | 1.64 | |
| Shyness | | | | −0.07 | −0.86 | | −0.08 | −0.97 | |
| RSA × Shyness | | | | | | | 4.45 | 2.35 | * |
| $r^2$ | 0.25 | | | 0.29 | | | 0.34 | | |
| Change in Model Fit | $D_m = 16.29, p < .001$ | | | $D_m = 2.51, p = .082$ | | | $D_m = 5.32, p = .019$ | | |

Note.

* $p < .05$

** $p < .01$

*** $p < .001$.