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How Biology Shapes the Development of Shyness Within Specific Contexts: A Longitudinal, Cross-Lagged Investigation

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Shyness is a temperamental trait that refers to fear and wariness in the face of social novelty and is known to have a biological basis. One proposed physiological correlate of shyness has been the change in respiratory sinus arrhythmia (RSA) from baseline to a stressor. However, past research linking shyness and RSA change has been mixed, which may be, in part, due to a failure to carefully consider the context under which RSA change is measured and the directionality of relations. Using a longitudinal design and cross-lagged analysis ($N = 103$, 52 girls), we examined parent-reported shyness and RSA change during a stranger approach task (social stressor) and a locked box task (nonsocial stressor) at ages 3 (M_{age} at Time 1 = 3.50 years, $SD_{\text{age}} =$ 0.19 years) and 4 (M_{age} at Time 2 = 4.76 years, $SD_{\text{age}} = 0.38$). Cardiac vagal withdrawal during the stranger approach task, but not during the frustration task, at age 3 positively predicted shyness at age 4. Shyness at age 3 did not predict cardiac vagal change in either context at age 4. We also found that changes in RSA measured during the frustration task were stable across time, but changes in RSA measured during the stranger approach task were not stable across time, suggesting a developmental change in physiological regulatory systems to social threat. These results suggest that, although biology may come first in shaping children's behavior, this relation depends critically on the context and the incentives in the child's environment.

Public Significance Statement

At age 3, cardiac vagal withdrawal, a physiological index of reactivity, was positively related to shyness 1 year later. This relation was specific to cardiac vagal withdrawal measured in a social threat context but not in a frustrating context that was less socially threatening. These results highlight the importance of considering context when examining biological factors that place individuals at greater risk of developing shyness.

Keywords: shyness, respiratory sinus arrhythmia, temperament, preschool

The study of biology and context in the development of shyness can be traced to the work described by Jerome Kagan and Howard Moss over 60 years ago in their seminal book, *Birth to Maturity* (Kagan & Moss, 1962). In that volume, Kagan and Moss reported on the observations collected as part of the Fels Institute's Longitudinal Project in which children and their families were followed longitudinally and observed across different contexts, including in their homes, their school environments, and the Fels Institute's nursery school. According to Kagan, "the only psychological quality preserved from the first 3 years of life through adulthood was the characteristic we now call behavioral inhibition, although we called it passivity in 1962" (Kagan, 1989, p. 668). Kagan and Moss had suggested at the time that this "predisposition might be a partial function of biological variables," but the Zeitgeist during the early 1960s largely eschewed the contribution of biology to behavior. Two decades later, Kagan and his graduate student

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Cynthia Garcia-Coll then formally described and systematically investigated the concept of behavioral inhibition (Garcia-Coll et al., 1984; Kagan et al., 1984) and its biological basis (Kagan et al., 1987, 1988). Behavioral inhibition reflects timidity and cautiousness in response to novel social and nonsocial incentives, has its roots in early infant reactivity, is associated with distinct central, autonomic, and neuroendocrine correlates, and is predictive of temperamental shyness (see Kagan, 1994, 1999, for reviews).

Although there has been a burgeoning interest in the study of behavioral inhibition and temperamental shyness over the last 40 years (Fox et al., 2001, 2005; Kagan, 1994, 2022), we know relatively little about the directionality of relations between biology and behavior in different contexts in the study of temperamental inhibition and shyness. Kagan (1994) theorized, and long presumed, that the child actively shapes their own behavior, but this process is also heavily dependent on contextual and environmental influences. The purpose of the present study was to empirically clarify the directionality of the complex relations between biology and behavior described in the extant literature in understanding the development of temperamental shyness in children.

Temperamental Shyness, Biology, and Context

Shyness is a moderately stable temperamental characteristic that refers to wariness and fear in new social situations (Kagan, 1994). Temperamentally shy children are known to be more avoidant in social situations. For example, shyness has been associated with a high and steeply increasing trajectory of a composite of behavioral avoidance in a threatening social situation in preschoolers (Hassan & Schmidt, 2021). Shy children are known to speak less in unfamiliar social situations (Asendorpf & Meier, 1993; Crozier & Perkins, 2002) and also appear to be at greater risk for developing peer-related difficulties (Coplan et al., 2008) and internalizing problems across development (Chronis-Tuscano et al., 2009; Findlay et al., 2009), especially symptoms of social anxiety disorder characterized by a fear of negative evaluation (Chronis-Tuscano et al., 2009; Clauss & Blackford, 2012; Fox et al., 2021, 2023; Heiser et al., 2003, 2009; Hirshfeld-Becker et al., 2007; Poole et al., 2017, 2020; Sandstrom et al., 2020). Given the biological basis of temperament broadly (Rothbart & Bates, 2006), and in a developmental antecedent of shyness in particular (Kagan, 1994; Kagan et al., 1987, 1988), some researchers have attempted to link individual differences in physiology to the development of shyness.

One physiological factor that has been implicated as an important correlate of shyness is parasympathetic control indexed via respiratory sinus arrhythmia (RSA). RSA reflects variability in heart rate occurring at the frequency of respiration and is thought to index the parasympathetic nervous system's influence on the heart through the vagus nerve (Porges, 2007). Much of the recent work on RSA in this domain has been guided by the Polyvagal Theory (Porges, 1995, 2007), which suggests that the development of the parasympathetic nervous system supports individuals' capacity for social engagement. In response to personally and emotionally evocative environmental stimuli, the regulation of emotional and social states occurs through the regulation of cardiac activity.

RSA can be measured at rest (i.e., baseline), during a task, or in baseline to task changes (i.e., cardiac vagal regulation). Resting RSA has been used as a measure of an individual's dispositional arousal level and a marker of the physiological system's efficacy in responding to environmental challenges (Porges, 1992; Thayer & Lane, 2000), where high values on this metric are typically associated with positive affective, social, and self-regulatory outcome (Calkins & Dedmon, 2000; Fabes & Eisenberg, 1997; Hansen et al., 2003; Huffman et al., 1998; Stifter et al., 1989). Stated differently, resting RSA has been thought of as a measure of regulatory potential, with higher levels of baseline RSA reflecting more potential for effective regulation.

Studies linking resting RSA and shyness and related constructs have been mixed. Some studies have found a negative association between resting RSA and behavioral inhibition (Fox, 1989), shyness more broadly (Doussard-Roosevelt et al., 2003) and only in the context of high-income neighborhoods (Zhang et al., 2018), social fear (Stifter & Jain, 1996), and social reticence (Henderson et al., 2004). As well, at least one study has found a significant association in the opposite direction (Dietrich et al., 2009). However, there are just as many recent and earlier studies that have failed to find a direct association between shyness and resting RSA (Hassan et al., 2020; MacGowan et al., 2022; MacGowan & Schmidt, 2020, 2021; Marshall & Stevenson-Hinde, 1998; Smith et al., 2019; Sulik et al., 2013; Viana et al., 2017).

Changes in RSA from baseline to a task (i.e., cardiac vagal change) may result in more consistent findings compared to baseline RSA in relation to shyness because cardiac vagal change is thought to reflect context specific, in the moment reactivity and regulatory efforts, rather than regulatory capacity. When faced with environmental challenges, individuals typically react with either cardiac vagal augmentation (baseline-to-task increases in RSA) or withdrawal (baseline-to-task decreases in RSA; see, Hastings & Kahle, 2019; Porges, 2007). Cardiac vagal augmentation is thought to support a relatively calm state and occurs when environmental stimuli are personally relevant and potentially challenging, but not threatening. Cardiac vagal withdrawal is thought to support a more alert state and occurs when environmental stimuli are personally relevant and potentially threatening. When perceived threat is low, cardiac vagal augmentation recruits fewer physiological resources and can support social engagement. When percieved threat is high, cardiac vagal withdrawal reflects less input from the vagal nerve, allowing for greater mobilization of physiological resources through an increase in sympathetic activation, supporting active coping. Depending on the context, cardiac vagal regulation in the form of either augmentation or withdrawal supports potentially more adaptive emotional and behavioral responses in the face of environmental challenges (Calkins, 1997; Calkins et al., 2007; Porges, 2001, 2003).

The relation between shyness and cardiac vagal change is also mixed, which may be, in part, due to inconsistencies in the contexts used to elicit change. Some studies have examined the relation between shyness and cardiac vagal change in a nonsocial context. For example, shyness was unrelated to changes in RSA measured from baseline to a receptive vocabulary test in children (MacGowan & Schmidt, 2020) and from a supine to a standing position in preadolescents (Dietrich et al., 2009). As shyness is defined as wariness in the context of social novelty (A. H. Buss, 1986; Cheek & Buss, 1981; Karevold et al., 2012; Sanson, 1996), it is not surprising that shyness was unrelated to a measure of physiological reactivity and regulation in a relatively nonsocial context (Dietrich et al., 2009; MacGowan & Schmidt, 2020).

Other studies have used either social stressors or a mix of social and nonsocial stressors to elicit cardiac vagal change. For example, one study found that parent-reported fearful temperament at 20 months was unrelated to cardiac vagal change averaged across a battery of social and nonsocial stressors at 24 and 42 months (Morales et al., 2015). A different study used the same battery of tasks to examine RSA in relation to parent-reported social inhibition rather than fearful temperament more broadly (K. A. Buss et al., 2018). We consider social inhibition the same as shyness because the three items used to measure social inhibition in the study by Buss and colleagues asked parents about their child's sensitivity toward social novelty (K. A. Buss et al., 2018). Although there were some variations in longitudinal relations between shyness and RSA during different tasks, RSA at 24 months was most consistently positively associated with shyness at 24, 36, and 48 months during social stressors and not during less social stressors (K. A. Buss et al., 2018). Using other contexts of social threat, at least two studies found that shyness was related to greater cardiac vagal withdrawal from baseline to a stranger approach task (Poole & Schmidt, 2021a) and in anticipation of self-presentation task (Poole & Schmidt, 2021b) during middle childhood, and one study found that shyness was not associated with cardiac vagal change during a stranger approach task concurrently at age 2 (Brooker & Buss, 2010).

The inconsistent findings between RSA and shyness may be due to a failure to consider context consistently. Shy children are not inherently dysregulated across contexts. Rather, shy individuals are thought to experience more anxiety and fear in new social situations (Cheek & Buss, 1981; Kagan et al., 1988; Karevold et al., 2012; Sanson, 1996). In support of this theoretical account, shy children spoke less in unfamiliar social situations than less shy children (Asendorpf & Meier, 1993; Crozier & Perkins, 2002) and were more likely to have playdates with their peers in their homes than outside their homes (Coplan et al., 2009). Shyness was also negatively associated with prosocial behavior in the laboratory but not at home (Stanhope et al., 1987), and when children had relatively high levels of inhibitory control, shyness was negatively associated with social support seeking from an unfamiliar adult, but not a familiar adult (Hassan & Schmidt, 2023). Together, these studies suggest shyness may be only associated with individual differences in cardiac vagal change in novel social contexts and may account for some of the inconsistent findings observed in a nonsocial context (Dietrich et al., 2009; MacGowan & Schmidt, 2020), a social context (Brooker & Buss, 2010; Poole & Schmidt, 2021a, 2021b), or a mix of social and nonsocial contexts to elicit cardiac vagal change (K. A. Buss et al., 2018; Morales et al., 2015). The importance of context is underscored by recent calls to carefully consider it in developmental psychobiology more broadly (Darling et al., 2022; Davis et al., 2020).

Another potential contributor to the inconsistent findings may be a failure to account for issues of directionality. Specifically, it is unclear if parasympathetic regulation measured via cardiac vagal change is perpetuating shyness, whether shyness is perpetuating cardiac vagal change, or whether these constructs are mutually reinforcing each other over developmental time. To address the question of directionality, it is important to implement a longitudinal design and employ statistical methods, such as cross-lagged analysis, that account for previous levels of cardiac vagal change across contexts and shyness over time. This type of design and analysis would allow a direct empirical test of Kagan's theoretical idea that the child's biology actively shapes their own behavior in different contexts (Kagan, 1994).

The Present Study

Considering the gaps in the literature, the goal of the present study was to examine the relation between shyness and cardiac vagal change from baseline to a social (stranger approach task) and less social stressor (locked box task) stressor from age 3 to age 4 using a cross-lagged design to clarify issues of directionality. Given the propensity for shy children to perceive social novelty as threatening, and following recent work (Poole & Schmidt, 2021a, 2021b), we predicted that shyness would be concurrently associated with cardiac vagal withdrawal during a social stressor (i.e., the stranger approach task), but not during a less social stressor (i.e., the locked box task). Following Kagan's seminal work suggesting that shyness has a biological basis (Kagan, 1994; Kagan et al., 1988), we predicted that cardiac vagal withdrawal at age 3 would be positively associated with shyness at age 4. We did not make other specific predictions regarding the bidirectionality of shyness and cardiac vagal change relations because of the lack of previous work that has examined issues of directionality on these relations using a cross-lagged design.

Method

Participants

Participants were 105 typically developing 3-year-old children (52 girls, $M_{\text{age}} = 3.50$ years, $SD_{\text{age}} = 0.19$ years) and their parents who were recruited from the Child Database in the Department of Psychology, Neuroscience & Behaviour at McMaster University in Southern Ontario, Canada. This database contains the names and contact information of parents of healthy, full-term newborn infants recruited from hospitals across the greater Hamilton metropolitan area who agreed to be contacted in the future to participate in infant and child studies conducted at McMaster University. Most of the children were White (87%), and their families had a mean household income of between $75,000 and $100,000 in Canadian dollars. Data collection occurred between 2017 and 2019.

Procedure

The present study was part of a larger project examining the influence of temperament on children's prospective social and emotional outcomes across the preschool period. Children and their parents visited the Child Emotion Laboratory at McMaster University at Time 1 (T1) when the children were 3-years-old ($M_{\text{age}} = 3.50$ years, $SD_{\text{age}} = 0.19$ years) and at Time 2 (T2) approximately 1 year later ($n = 72$, M_{age} at T2 $= 4.76$ years, $SD_{\text{age}} = 0.38$). The procedures and measures were identical at each visit.

At each visit, the child, mother, and one female experimenter began in a room together. While the child played with a puzzle, the experimenter explained the study procedures to the mother. Once the child was acclimated to the room, the mother went into a separate room to complete a series of questionnaires. She could view her child on a closed-circuit computer monitor. To obtain baseline RSA, the child was instructed to do their best to sit still while they quietly watched a five-and-a-half-minute neutral movie clip, and then the child was exposed to the stranger approach task (social context) followed by the locked box task (less social context) where RSA was also obtained (Goldsmith et al., 1995).

The stranger approach task was heavily adapted from the stranger approach episode from the preschool Laboratory Temperament Assessment Battery (Lab-TAB; Goldsmith et al., 1995). While the child was seated at a table, the experimenter told the child that she had to go get something from the other room and that she would be right back. After 10 s, an unfamiliar research assistant (RA) wearing sunglasses and a hat entered the room and proceeded to try to engage the child using a standardized script, getting closer and closer to the child with each utterance (see Goldsmith et al., 1995, for the full script). The unfamiliar RA then told the child "I came looking for a paper, was there a woman in here?" and left the room to go wait in the hall. The original experimenter then reentered the room and gave the stranger a piece of paper in front of the child, and the episode ended. This was considered a social stressor because the child had never met the stranger before. The only difference in procedures between the original Lab-TAB and those used in the present study was that the child was seated rather than standing so RSA could be meaningfully compared from baseline to the task.

The locked box task was heavily adapted from the Attractive Toy in a Transparent Box episode from the preschool Lab-TAB (Goldsmith et al., 1995). During this task, the child was presented with three toys and asked to select which toy they liked the best. Following selection, the unwanted toys were removed from the child's view, and a transparent, plexiglass box was placed on the table. The child was then told "Now I am going to show you how we play this game. I'm going to take [name of the toy] and put it in this box. And then I'm going to put a lock on it. You are going to use these keys to open this lock, and when you do, you can play with [name of the toy]." The toy was then locked up and the child was presented with a large set of keys, none of which opened the lock. The correct key was hidden away, and the child had not seen the key. The experimenter pretended to work sitting adjacent to the child for the next 4 min. If the child attempted to elicit help from the experimenter, he or she was told "I have some work to do. You get [name of the toy] out all by yourself." After 4 min passed, the experimenter brought the correct key into view and told the child "I just found this extra key. Do you think maybe this one opens the lock?" The experimenter then helped the child get the toy out of the box using the correct key. This was considered a nonsocial stressor because it was frustrating, and the experimenter by this time had become familiar to the child having had spent at least 40 min with them in the lab playroom while the child was trying to open the locked box. The only difference in procedures between the original Lab-TAB and those used in the present study was that the child was with the experimenter rather than in the room alone during the episode.

Mothers provided written consent and children provided verbal assent at each visit prior to the commencing of any procedures. All families were provided with small toys, Junior Scientist certificates, and a gift card ($10 CAD at T1, $20 to $30 CAD at T2) as tokens of appreciation for their participation at each visit. All procedures were approved by the McMaster Research Ethics Board (Title: Private Speech and Physiological Measures of Self-Regulation, Protocol Number: 2052).

Measures

Shyness

Shyness was mother-reported using the six-item shyness subscale from the Children's Behavior Questionnaire (Rothbart et al., 2001) at T1 and T2. Statements were rated by mothers on a scale ranging from 1 (*never*) to 7 (*always*). A sample item from the shyness scale includes "acts shy around new people." The shyness scale demonstrated very good internal consistency at T1 ($\alpha = .89$) and T2 ($\alpha = .93$).

RSA Data Collection

Cardiac and respiratory data were collected using the MindWare Mobile Impedance Cardiograph, Model 50-2303-00, with a sampling rate of 500 Hz and 24-bit analog to digital conversion digitization. Following MindWare's recommendation to use a modified lead II configuration, cardiac data were recorded from three electrodes affixed to the child's upper right back and lower left and right sides. The ground electrode was the one affixed to the child's lower right back. We elected to place the electrodes on the child's back rather than the chest because children were less likely to fidget with the wires when the electrodes were affixed to the back. The mobile cardiograph was then placed in a backpack that the child wore for the duration of the study. Respiration data were recorded from a respiratory strain gauge placed around the child's chest.

RSA Data Reduction and Quantification

The cardiac and respiratory signals were reduced and analyzed using a commercial software package (MindWare HRV 3.1.1, MindWare Technologies, Ltd.), and edited by hand for spurious or missing beats according to recommendations reported elsewhere (Berntson & Stowell, 1998). Because the focus of the study was preschool-aged children, we used a respiratory frequency of 0.24–1.04 Hz, which is commonly used for young children (Porges et al., 2007). Baseline RSA was estimated by averaging the mean RSA from five 1-min-long segments while the child watched a neutral video clip. On task RSA was computed from two 1-min-long segments while the child was exposed to the stranger approach task, and the four 1-min-long segments while the child was exposed to the locked box task. Cardiac vagal change was operationalized as baseline RSA minus on task RSA during the stranger approach and locked box tasks. On this metric, lower values reflect vagal augmentation (increases in RSA from baseline to a task) and higher values reflect vagal withdrawal (i.e., decreases in RSA from baseline to a task).

Missing Data and Loss to Follow-Up

Of the 105 children at T1, 13 to 15 were missing RSA, depending on the task, due to equipment failure or refusal to participate, and two were missing maternal report of shyness. Of the 105 children, 71 returned approximately 1 year later for a second visit (T2). Of the 71, 20 were missing RSA due to equipment failure, too much noise in the electrocardiography signal, or refusal to participate.

The children who did not have T2 data did not differ from those children who did based on age, $t(102) = 0.25$, $p = .73$, sex, $\chi^2(1) = 1.01$, $p = .33$, household income, $t(97) = -1.08$, $p = .28$, T1 shyness, $t(85) = -0.16$, $p = .87$, and T1 vagal regulation during the strange approach, $t(90) = -1.17$, $p = .25$, or locked box task, $t(88) = -0.99$, $p = .32$.

Little's test of missing completely at random (MCAR) was not significant, $\chi^2(509) = 164.36$, $p = 1.00$, suggesting that patterns of missing data did not violate the assumption that data were MCAR. To leverage the complete sample at T1, full information maximum likelihood (FIML) was used to account for missing data in the cross-lagged model. Because of overlap in missing data, a total of 103 children at T1 contributed data for at least one variable and were included in the cross-lagged model. FIML uses all available raw data to simultaneously account for all the missing data and estimates model parameters and standard errors simultaneously, thus avoiding the biased parameter estimates that can occur with pairwise or listwise deletion (Schafer & Graham, 2002).

Statistical Analyses

The present study used a cross-lagged model to examine the associations among shyness, cardiac vagal change during the stranger approach task (a social threat), and during the locked box task (a less social frustration task) at T1 and T2. To mirror other studies that control for baseline RSA when examining the relation between temperament and cardiac vagal change (Bornstein & Suess, 2000; Calkins & Keane, 2004; El-Sheikh, 2005; Graziano & Derefinko, 2013), a standardized residual of the vagal regulation variables controlling for baseline RSA at T1 and T2 was computed. We controlled for sex and age in the cross-lagged model because of differences in the relation between fearful temperament and cardiac vagal change (Morales et al., 2015) and age-related differences in stranger fear (Brooker et al., 2013) and cardiac vagal change (Calkins & Keane, 2004; El-Sheikh, 2005). The analyses were conducted in MPlus Version 8 using an MLR estimator.

Cross-lagged models provide us with three important pieces of information in one parsimonious model. Autoregressive relations indicate whether a construct is stable over time; cross-lagged relations indicate whether relations across time between variables are unidirectional, bidirectional, or nonsignificant; and residual relations indicate whether concurrent relations among the variables are significant. Model fit was evaluated using root-mean-square error of approximation (RMSEA) with a cutoff of .05, standardized root-mean-square residual (SRMR) with a cutoff of .08, Comparative Fit Index (CFI) with a cutoff of .95, and the Tucker–Lewis Index (TLI) with a cutoff value of .95 (Hu & Bentler, 1999). Data that support the results reported in this article are available upon request. This study was not preregistered.

Results

Descriptive Statistics and Model Fit

The means and *SD*s of shyness, cardiac vagal change during the strange approach task, and cardiac vagal change during the locked box task are presented in Table 1. The cross-lagged model exhibited excellent model fit, $\chi^2(6) = 3.89$, $p = .69$, RMSEA = 0, 90% $CI_{RMSEA} = [0–.09]$, SRMR = .04, CFI = 1, TLI = 1. The results from the cross-lagged model below include age and sex as covariates. That pattern of results remains unchanged when removing the covariates.

Autoregressive Relations

As shown in Figure 1, shyness ($B = .73$, $p < .001$) and cardiac vagal change during the locked box task ($B = .44$, $p < .001$) were stable from T1 to T2. Cardiac vagal change during the stranger approach task was not stable across time ($B = .001$, $p = .997$).

Cross-Lagged Relations

As shown in Figure 1, shyness at T2 was positively predicted by cardiac vagal withdrawal during the stranger approach task at T1 ($B = .31$, $p = .043$), but not by cardiac vagal change during the locked box task at T1 ($B = -.03$, $p = .801$). Cardiac vagal change during the stranger approach at T2 was positively predicted by cardiac vagal withdrawal during the locked box task at T1 ($B = .30$, $p = .046$), but not by shyness at T1 ($B = -.15$, $p = .088$). Cardiac vagal change during the locked box task at T2 was not significantly predicted by either vagal change during the stranger approach task ($B = .11$, $p = .475$) or shyness at T1 ($B = -.05$, $p = .607$).

Residual Correlations

As shown in Figure 1, concurrently at T1 ($B = .38$, $p < .001$) and T2 ($B = .33$, $p = .033$), cardiac vagal change during the stranger approach and locked box task were positively related. Shyness was unrelated to cardiac vagal change during the stranger approach task and during the locked box task at T1 and T2 (*p*s $\geq .350$).

Discussion

In the present study, we used a longitudinal design and cross-lagged analysis to examine concurrent and longitudinal relations between shyness and cardiac vagal change during a social stressor and less social stressor from age 3 to 4 in typically developing preschoolers. The goal of the present study was to clarify the directionality of the relations between shyness and cardiac vagal change and

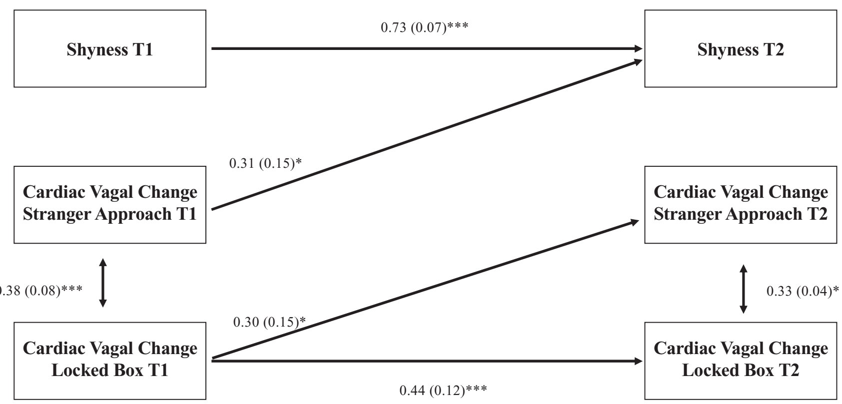
Table 1
Descriptive Statistics for All Study Variables

Variable	*M* (*SD*)	Range	*n* contributed
T1 shyness	3.53 (1.25)	1 to 6.67	103
T1 stranger approach cardiac vagal change	−0.12 (0.89)	−4.19 to 2.45	90
T1 locked box cardiac vagal change	0.14 (0.83)	−1.58 to 2.27	92
T2 shyness	3.46 (1.21)	1.17 to 6.33	64
T2 stranger approach cardiac vagal change	−0.01 (0.64)	−2.02 to 2.45	49
T2 locked box cardiac vagal change	0.54 (0.73)	−1.76 to 2.74	48

Note. T1 = Time 1; T2 = Time 2.

Figure 1

Cross-Lagged Model Including Associations Between Children's Shyness and Cardiac Vagal Change During the Stranger Approach Task and Locked Box Task at T1 and T2, Controlling for Sex and T1 Age



Note. Values represent unstandardized coefficients and standard errors in brackets. Only significant paths are denoted. T1 = Time 1; T2 = Time 2.
* $p < .05$. *** $p < .001$.

to examine if these relations depend on different contexts. We found that cardiac vagal withdrawal (i.e., a decrease in RSA from baseline to a stressor) during a social stressor at age 3 was positively associated with shyness at age 4. This relation was specific to the social context, as cardiac vagal change during a relatively less social stressor at age 3 was not associated with shyness at age 4. We also found that indices of cardiac vagal change across the two different contexts were concurrently positively associated at ages 3 and 4 and that cardiac vagal change during the nonsocial context at age 3 was positively associated with cardiac vagal change in the social context at age 4. We found support for stability in shyness from age 3 to 4, and cardiac vagal change during the locked box task from age 3 to 4, but not in cardiac vagal change during the stranger approach task.

We also found that cardiac vagal change was stable across time during a relatively nonsocial stressor, thought to elicit frustration, but not during a social stressor thought to elicit social fear (Goldsmith et al., 1995). Other studies have found support for stability in cardiac vagal change over time from 24 to 42 months averaged across several social and nonsocial stressors (Morales et al., 2015) and from a mean age of approximately 9–11 years during a sustained attention task, but not during a task where children listened to an argument between adults (El-Sheikh, 2005), and not from infancy to 5 years during an age-appropriate attention-based task (Bornstein & Suess, 2000). Another study found stability in cardiac vagal change across some tasks but not others, including a frustration task similar to the one used in the present study, from age 2 to 4.5 years (Calkins & Keane, 2004). Differences may have emerged because we used the same task over time, whereas the previous study used different age-appropriate measures of frustration-eliciting tasks over time, and the developmental window was more narrow in our study (Calkins & Keane, 2004). Together, these studies suggest that there is some stability in cardiac vagal change during childhood, but that stability may depend on context and developmental time (Bornstein & Suess, 2000; Calkins & Keane, 2004; El-Sheikh, 2005; Morales et al., 2015).

Our study makes a unique contribution by examining stability during a social stressor versus a frustrating less social stressor over time. At least one study has examined the normative development of parent-reported stranger fear across several visits from 6 to 36 months (Brooker et al., 2013), and these authors found that stranger fear continued to increase from 22 to 36 months. It is also important to note, however, that there may be mean-level changes in stranger fear from 3 to 4 years, which may impact vagal change during the stranger approach task. The lack of stability in cardiac vagal change during the stranger approach task in the pattern of results also suggests that there may be developmental changes in physiological regulatory processes in response to social threat at this age.

Regarding the less social stressor, no studies to our knowledge have yet examined the stability of frustration in children, so it is difficult to determine whether the meaning or impact of the frustration task used in the present study was similar at age 3 and 4. As it is impossible to open the locked box in the frustration task used in the present study, the increases in self-regulation that occur across the preschool years may not meaningfully contribute to children's interpretation of the task (Dennis et al., 2007; Geeraerts et al., 2021; Klenberg et al., 2001; Kochanska et al., 1996; Schoemaker et al., 2014; Williams et al., 1999). However, we speculate, based on the results of the present study, that cardiac vagal change during a frustration task may be more stable from 3 to 4 years because children's frustration-based responses in a nonsocial context may be more stable than their responses to a stranger approach task.

Although not the primary focus of the present study, we also found that cardiac vagal change during the frustration task at age 3 was positively associated with cardiac vagal change during the stranger approach task at age 4, but not vice versa. Our results are consistent with at least one previous study suggesting that cardiac vagal change during a frustration task at 2 years old is prospectively associated with cardiac vagal regulation across other contexts tapping different emotions or skills at 4.5 years old (Calkins & Keane, 2004). One potential reason may be that the physiological responses to social fear are more specific than physiological responses to frustration. Perhaps physiological responses to frustration are related to greater reactivity in general, including prospective physiological responses to interacting with strangers.

Following Kagan's work suggesting a biological basis for individual differences in temperament (see Kagan, 1994), we found that cardiac vagal withdrawal perpetuated shyness over time and that shyness did not perpetuate cardiac vagal withdrawal. Compared to cardiac vagal augmentation (increases in RSA from baseline to a challenge), cardiac vagal withdrawal (decreases in RSA from baseline to a challenge) is thought to support a more alert state because the vagal brake is lifted, allowing for more sympathetic versus parasympathetic influence (Hastings & Kahle, 2019; Porges, 2007). Cardiac vagal withdrawal occurs when cues in the environment are personally relevant and threatening. One review on the topic has suggested that higher levels of cardiac vagal withdrawal during perceived threat may reflect more emotional liability rather than effective emotion regulation (Beauchaine, 2001). In line with this view, we speculate that children who have a relatively lower threat sensitivity reflected in the greater mobilization of physiological resources through greater cardiac vagal withdrawal in the presence of social novelty may predispose them to developing shyness. One alternative explanation is that differences in the relations between shyness and cardiac vagal change during the stranger approach versus a locked box task over time occurred because of task intensity rather than social versus less social context. To our knowledge, no study has attempted to examine or match the intensity of different Lab-TAB episodes. We, therefore, cannot rule out task intensity as a contributor to the observed relations.

Practical and Theoretical Implications

Our results also have practical implications that warrant discussion. Previous work examining the relation between shyness and cardiac vagal change in a nonsocial context (Dietrich et al., 2009; MacGowan & Schmidt, 2020), a social context (Brooker & Buss, 2010; Poole & Schmidt, 2021a, 2021b), or some combination of social and nonsocial contexts to elicit cardiac vagal change (K. A. Buss et al., 2018; Morales et al., 2015) has been mixed. Most consistently, significant relations emerged in studies using a social stressor to elicit cardiac vagal change. Our results suggest that it is important to anchor the context used to elicit cardiac vagal change theoretically to the temperamental variable under consideration. In this case, cardiac vagal change during social stressor may be linked more strongly to shyness than other nonsocial stressors.

We also extended previous work that demonstrated a concurrent relation between shyness and cardiac vagal withdrawal to social stressors during middle childhood (Poole & Schmidt, 2021a, 2021b) to a longitudinal framework and clarified issues of directionality during the preschool period. However, unlike these recent studies by Poole and Schmidt (2021a, 2021b), we did not find evidence of concurrent relations between shyness and cardiac vagal withdrawal in the present study. There seem to be at least three reasons for the lack of concurrent relation.

One reason might be differences in the age of participants. Poole and Schmidt examined older children in middle childhood; whereas in the present study, we examined preschoolers, so there may be unmeasured age-related changes that contribute to these different patterns of concurrent and predictive relations. A second reason, related to the first, is a developmental explanation. It is possible that the relation between shyness and cardiac vagal withdrawal becomes canalized with age, increasing the likelihood of finding significant concurrent relations with older children and adults, while physiology predicts features of shyness that are not necessarily solely dependent on this canalization process across development. A third reason might lie in the sensitivity of the measure. It is possible that the cardiac vagal withdrawal measure is simply more sensitive to detecting prospective than concurrent relations.

The present findings have implications for Kagan's long-standing ideas and theory. Over six decades ago, Kagan was already keenly aware of the importance of biology and its role in predisposing children to different temperamental qualities. He was also astutely cognizant of the need to study children in varying contexts to see if, and how, these different environments in combination with biology altered the privileged role of biology in personality development (Kagan, 2003, 2022; Kagan & Moss, 1962). In the present study, we found empirical evidence in support of Kagan's idea that biology actively shapes behavior and personality development, and this process is dependent on the context and environment in which the child develops. In our study, change in cardiac vagal withdrawal in the third year of postnatal life predicted children's shyness at age 4, but only in a social threatening context. These results suggest that some children may be biologically predisposed to shyness and inform the role of biology and context in understanding in individual differences in personality and socioemotional development.

Strengths, Limitations, and Future Directions

The present study had several strengths that should be noted. These included: the use of a longitudinal design, an analytical approach that allowed for clarification of directionality issues, the inclusion of physiological data measured in different contexts, and an examination at a critical developmental preschool age before formal school entry and when social shyness is theorized to emerge (A. H. Buss, 1986).

The present study also had several limitations that should be discussed so the results can be appropriately contextualized. First, the sample used in the present study was relatively homogenous as participants were typically developing, primarily White, and the mean household income was relatively high. Accordingly, our results might not be generalizable to children from more socioeconomically disadvantaged homes and ethnically diverse backgrounds.

Second, the number of participants lost to follow-up in the present study was relatively high, and equipment failure led to additional data loss. Importantly, missingness was not associated with any of the T1 variables of interest or sociodemographic information, the patterns of missing data did not violate the assumption that data were MCAR, and we used missing data handling techniques that should theoretically lead to less biased estimates than listwise deletion (Schafer & Graham, 2002).

Third, although participants were exposed to a social and less social stressor to elicit cardiac vagal change, another limitation of the contexts is the use of adult RAs in a laboratory setting rather than peers in a more naturalistic setting. It is possible that shy children's physiological responses vary in the laboratory versus in more familiar everyday contexts (e.g., at home or at school), and during interactions with same-age peers versus adult RAs. These nuances also limit the external validity and generalizability of our findings.

Fourth, although the preschool period is developmentally important because children have more volition over self-regulatory processes (Kochanska et al., 2001) and social shyness is presumed to emerge during this time, there are other developmentally important periods where shyness continues to develop, including during adolescence and adulthood (Brook & Schmidt, 2022; Tang et al., 2017). It would be important to examine whether early cardiac vagal withdrawal continues to perpetuate shyness across different developmental periods and if these relations become bidirectional later in development.

Fifth, although we elected to focus on cardiac vagal change to empirically evaluate Kagan's theoretical claims about the role of biology in predisposing children for different temperamental qualities such as shyness (Kagan, 2003, 2022; Kagan & Moss, 1962), there are other biological and physiological processes that may contribute to the development of shyness. Future studies can index these processes via methods such as electroencephalogram, skin conductance, and salivary cortisol.

Future studies should replicate the present study over a longer developmental period, using different contexts to elicit cardiac vagal change and methods indexing other biological and physiological processes, and in a larger and less ethnically and socioeconomically homogenous sample to ensure the reliability and generalizability of the present findings. As well, given the longstanding appreciation that Kagan had for the broader cultural contextual meaning and influences on understanding these complex relations (Kagan, 2010; Kagan et al., 1994; Kagan & Klein, 1973), and recent empirical work illustrating cross-cultural differences in children's shyness and its expression to differences in socioemotional outcomes (Kong et al., 2023; Xu et al., 2020), future work should consider examining the complex relations between biology and behavior in the child's everyday environments within broader developmental and sociocultural contexts.

Conclusion

We used a longitudinal, cross-lagged design to clarify the directionality of relations between children's shyness and cardiac vagal change in a social and less social context from age 3 to 4. We found that shyness and cardiac vagal change during a relatively nonsocial frustration task were stable over time. We also found that cardiac vagal change during a relatively nonsocial frustration task at age 3 was positively associated with cardiac vagal change during a social stressor task at age 4, and that cardiac vagal change during a social stressor at age 3 was positively associated with shyness at age 4. From a measurement perspective, these findings highlight the importance of using theoretically relevant contexts to induce cardiac vagal change when attempting to link cardiac vagal change with any outcomes (e.g., temperament, behavior). Theoretically, these findings are in keeping with Kagan's (Kagan, 2022; Kagan & Moss, 1962) long-standing idea that biology shapes human behavior but not isolation, as context also heavily contributes to the richness of the range of individual differences observed in temperament outcomes.

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