Early Temperament, Cortisol and Vagal Regulation Independently Predict Dimensions of Social Withdrawal in Childhood

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Abstract

Objectives were to examine whether 1) temperament and cortisol response in situations of unfamiliarity at 19 months predict social wariness and preference for solitude throughout childhood; 2) these predictive associations vary as a function of vagal regulation. Participants were 1199 children from the Quebec Newborn Twin Study, followed from 5 months to 10 years old (51% girl; 86% White). Findings show that behavioral inhibition to social unfamiliarity independently predicted both dimensions of social withdrawal in preschool. Low vagal suppression exacerbated the risk associated with negative affect manifested in unfamiliar situations to predict preference for solitude in preschool. In contrast, high vagal suppression increased the risk associated with strong cortisol response to unfamiliarity to predict social wariness in grade school.

Socially withdrawn children refrain from initiating interactions with other children and often find themselves isolated from the peer group (Rubin et al., 2009). Consequently, they may face increased risk for socioemotional difficulties, including internalizing and peer problems (Coplan et al., 2013). Difficulties in adapting to daily social stressors, for instance getting acquainted with new peers at school or asking a question to adults, may be rooted in both temperamental and biological dispositions such as early behavioral and physiological reactivity in contexts of unfamiliarity (Fox et al., 2005). Thus, early individual differences in behavioral inhibition, affect and cortisol responses to unfamiliar stimuli may represent early indicators of social withdrawal (Blair et al., 2004; Pérez-Edgar et al., 2011). However, research suggests that the level of risk associated with the development of social withdrawal is a function of the activation of the parasympathetic nervous system, such as indexed by vagal regulation (Blair et al., 2004). As few studies have examined these early precursors and only concomitantly, it remains unclear whether these putative precursors, i.e., behavioral inhibition, affect and cortisol, uniquely and additively predict later social withdrawal, and whether vagal suppression moderates these predictions. Documenting early temperamental and biological dispositions in unfamiliar contexts, as well as factors that may protect against or exacerbate these early dispositions are crucial steps in understanding the developmental mechanisms underlying social withdrawal.

Behavioral Inhibition and Affect

In the context of novelty (e.g., new people or objects), a significant group of toddlers tend to be highly reactive and manifest signs of elevated discomfort, such as crying (Garcia-Coll et al., 1984). Longitudinal studies indicate that these temperamental manifestations of behavioral inhibition and negative affect in the first years of life predict social withdrawal years later (Fox et

al., 2005). Children's reactions to unfamiliarity have typically been classified into high or low reactive profiles and thus considered under the same unidimensional umbrella, i.e., as a temperamental trait (e.g., Garcia-Coll et al., 1984). However, some studies show that although related, behavioral inhibition and affect are complementary and uniquely predict later internalizing difficulties, suggesting that they may reflect partially distinct components of temperament in early childhood (Putnam & Stifter, 2005). Therefore, behavioral inhibition and affect ought to be considered independently to more precisely depict the role of early temperament in the development of social withdrawal.

In addition to those behavioral markers of behavior inhibition, the cortisol response to stress, glucocorticoid stress hormone secreted by hypothalamic-pituitary-adrenal (HPA) axis activity, has also been identified as a key etiological factor in the onset and persistence of social withdrawal (Gunnar et al., 1997; Smider et al., 2002). High reactivity to unfamiliarity in toddlerhood, captured by elevations in cortisol levels detected in the saliva (Ouellet-Morin et al., 2008), may reflect a physiological component linking early inhibition and later social withdrawal in the context of unfamiliarity (Gunnar et al., 1997). Therefore, individual differences in cortisol secretion in novel or unfamiliar contexts may provide a unique window into children's temperamental and biological dispositions to social withdrawal.

The Possible Role of Cardiac Vagal Tone

Prior studies show that not all inhibited and reactive infants eventually become socially withdrawn or anxious (Degnan & Fox, 2007). Indeed, the capacity to regulate emotional responses through vagal suppression could buffer the risk associated with early temperamental and biological vulnerabilities (Smith et al., 2019). The cardiac vagal tone, a marker of autonomic

regulation activated by the vagus nerve, reflects children's parasympathetic regulation of the stress response and could facilitate the post-stress return to pre-stress baseline levels (Porges, 2007). Vagal suppression (i.e., vagal decrease from baseline to challenge tasks) is thought to facilitate the sympathetically mediated response, which favors optimal engagement to cope efficiently with environmental demands (Porges, 2007). Accordingly, children who show low vagal suppression in challenging situations may have greater difficulty to physiologically adapt to social stressors and thus manifest withdrawn behaviors in an attempt to reduce the onset or intensity of these stress responses (Graziano & Derefinko, 2013). However, other studies also suggest that *excessive* vagal suppression may be a sign of over vigilance and emotional vulnerability to potential threats and could thus exacerbate the risk of developing internalizing difficulties (Beauchaine, 2001; Calkins et al., 2007). Thus, the role of vagal regulation in the development of social withdrawal appears to be complex, and may be better understood in synergy with early temperamental and biological dispositions (Blair et al., 2004).

To date, no study has examined the extent to which vagal regulation uniquely interacts with behavioral inhibition, affect and cortisol response to predict later social withdrawal. As such, it remains unclear whether vagal regulation attenuates or exacerbates the risk associated with these early dispositions.

Social Wariness and Preference for Solitude

Despite these advances regarding the early precursors of social withdrawal, a major gap in knowledge relates to the factors driving the development of specific dimensions of social withdrawal. Social withdrawal is an umbrella construct covering various underlying dimensions, including social wariness and preference for solitude (Rubin et al., 2009). Social wariness and

preference for solitude are distinct dimensions of social withdrawal that are uniquely associated with socioemotional difficulties (Coplan et al., 2013; Morneau-Vaillancourt et al., 2021). In situations of social novelty, socially wary children typically experience heightened levels of anxiety and, as a result, avoid approaching unfamiliar people (Degnan et al., 2008). By contrast, children who prefer solitude do not necessarily experience negative emotions due to being socially isolated, as they are inclined to do things on their own (Coplan et al., 2013). Therefore, as they tend to be manifested in different social contexts (i.e., unfamiliar versus familiar) and differ in regard to their respective associations with socioemotional difficulties, social wariness and preference for solitude could result from distinct etiological influences and developmental pathways (Morneau-Vaillancourt et al., 2021).

Preliminary evidence indicates that distinct forms of behavioral inhibition underlie the development of social wariness and preference for solitude (Kochanska & Radke-Yarrow, 1992). Inhibition to unfamiliar *people* (i.e., social inhibition) versus inhibition to unfamiliar *settings* or *objects* (i.e., non-social inhibition) have been found to be only weakly correlated, suggesting that they may represent different behavioral tendencies, which in turn could differently predict dimensions of social withdrawal (Dyson et al., 2011; Kochanska & Radke-Yarrow, 1992; Rubin et al., 1997). For instance, Kochanska and Radke-Yarrow (1992) found that social inhibition in toddlerhood, defined as fear of strangers, was predictively associated with social wariness, whereas “non-social inhibition”, defined as reticence to explore new environments or objects, rather predicted a lack of involvement in group play. Therefore, some evidence suggests that social inhibition (i.e., behavior inhibition regarding a stranger) may be a precursor of later social wariness, while “non-social inhibition” is more closely related to later preference for solitude.

There is also empirical evidence to suggest that cortisol is independently associated with specific dimensions of social withdrawal. To the extent that socially wary children experience greater anxiety than children who prefer solitude (Coplan et al., 2013), they may show stronger cortisol reactivity in socially stressful situations than children who prefer solitude (see Davis & Buss, 2012; Schmidt et al., 1997). Yet, few studies have documented the association between cortisol and preference for solitude. One study showed that children who consistently prefer solitary activities have strong cortisol response to social situations (Gunnar et al., 1997). It may be that children who prefer solitude experience heightened stress in stimulating group, even if they suffer less from being socially isolated (Coplan et al., 2013). However, no study has yet compared the cortisol responses associated with social wariness versus preference for solitude.

To this already complex predictive equation, one has also to consider the possible moderating role of vagal tone. Indeed, there is evidence suggesting that vagal tone may play a moderating role in exacerbating the risk of developing social wariness specifically (Hastings et al., 2008, Rubin et al., 1997). For children who already experience elevated stress in social situations, having difficulties in regulating heart responses is likely to exacerbate their physiological (cortisol) and emotional (e.g., distress) responses (Buss et al., 2018). As these children experience more discomfort, they may prefer to avoid interacting with unfamiliar people and, over time, be more prone to exhibit social wariness (Buss et al., 2018). To the extent that children who prefer solitude also experience heightened stress in group contexts (Gunnar et al., 1997), similar patterns of associations between vagal suppression and preference for solitude could be found. However, the moderating role of vagal suppression in predicting preference for solitude remains largely undocumented.

The Present Study

To address current knowledge gaps in the etiology of social withdrawal, the present study used follow-up data from a prospective longitudinal cohort, collected over a 10-year period through various methods and informants (i.e., observation of behavior in unfamiliar situations, biological samples, behavioral evaluations from mothers, teachers and peers). The objective was to examine the extent to which behavioral inhibition, affect and cortisol responses in unfamiliar situations, measured at 19 months, independently or in interaction with prior individual differences in vagal suppression, assessed at 5 months, predict social wariness and preference for solitude in early (4 and 5 years old) and middle childhood (6 to 10 years old), that is, before and after transition to formal schooling. Indeed, the transition to formal schooling brings additional social demands, including adults' expectations about children's capacity to interact with peers and to regulate themselves in social contexts. If this is true for all children, it may be particularly stressful for socially withdrawn children (Rubin et al., 2009). However, previous studies were mostly cross-sectional or included follow-ups conducted over a short period of time, Therefore, the present longitudinal and multi-informant study aimed to investigate the developmental pathways both before and after this critical transition period. Social wariness was defined as an anxious form of social withdrawal in the presence of unfamiliar peers, and preference for solitude was defined as an inclination for solitary activities in group contexts. Since the present study is based on strong empirical and theoretical background and aims to test specific predictions in a large population-based sample, the analyses described below can be considered confirmatory.

Method

Participants of the Quebec Newborn Twin Study

Participants were from the Quebec Newborn Twin Study, an ongoing prospective longitudinal study. After getting access to birth records of newborn twins from the Quebec Bureau of Statistics, the QNTS recruited 662 families in the greater Montreal area, Canada, between April 1995 and December 1998. At recruitment, families in the sample were representative of the greater Montreal area population in the mid-1990s in terms of sociodemographic characteristics (see Boivin et al., 2019 for more information). Participants were assessed on a range of familial, behavioral, social and educational characteristics from birth to early adulthood. The present study used data collected over multiple waves, starting with laboratory assessments of vagal suppression at 5 months and of behavioral inhibition, affect and cortisol response at 19 months. In addition, mothers reported their children's social wariness and preference for solitude at 4 and 5 years old, whereas teachers and peers completed these reports when the target child was 6, 7 and 10 years old. Among the participants included in the present study (51% girl), 86% were White, 5% were Black, 3% were Asian and less than 1% were from First Nations communities in Canada.

The number of participants for each variable of interest varied across assessment waves. Due to a decrease in financial resources available and to the high cost of laboratory assessments, fewer participants were assessed in the laboratory at 5 and 19 months ($N = 564$). The number of participants for whom social wariness and preference for solitude was evaluated at 4, 5, 6, 7 and 10 years old varied from 779 to 883. In the final model, 1199 participants were included, as these participants had available data for at least one variable (using a robust maximum likelihood estimator, see below for a description of analyses). The model was also tested using data from

the 564 participants at 5 or 19 months (see sensitivity analyses presented in the Supplement).

Missing data were missing at random (MAR) for the most part (for a description of missing data analyses, see the Supplement).

Ethical Considerations

For all follow-up assessments, parental informed consent and child assent were obtained, and ethics review boards at Université Laval in Québec City and at Université de Montréal and Ste-Justine Hospital in Montréal approved the procedure.

Measures and Procedures

Assessment of Vagal Tone at 5 Months

At approximately 5 months (mean [M] = 5.27, standard deviation [SD] = .64), mothers and children visited the laboratory in Montréal, Canada. Assessment of vagal tone through electrocardiograms is described elsewhere (see Poliakova et al., 2014). Heart frequency estimates within a 0.15-1.0 Hertz bandwidth were obtained by the mean of the autoregressive (AR) forward-backward linear least-squares method with a 20th-order using Heart Rate Variability Analysis Software 1.1.

Baseline Vagal Tone. To assess baseline vagal tone, electrocardiograms were recorded twice over 4-minute periods when young children were sleeping in a reclining car seat in a horizontal posture and then in a vertical posture (after a period of 60 seconds following vertical tilt to allow vagal tone to stabilize first). Distribution of vagal tone in horizontal and vertical resting positions were positively skewed and were thus log-transformed. Since they were highly

correlated ($r = .78, p < .01$), the mean across both resting positions was used as baseline vagal tone.

Vagal Tone in Challenging Tasks. Then, to assess vagal tone in situations of mild stress and stimulation, participants took part in three conditions: two unfamiliar tasks, a habituation and a mobile task and an infant-mother interaction. These tasks are described in more details in the Supplement. Since vagal tone correlations between the three tasks were moderate to strong (r across the three tasks = .49-.59, $p < .01$), challenge vagal tone was averaged over the three tasks. Vagal suppression scores were obtained by computing the difference between challenge and baseline vagal tone (i.e., vagal suppression = challenge - baseline) (e.g., Graziano et al., 2007). Low or negative scores indicated larger decrease from baseline to challenge and thus a diminished parasympathetic influence on the heart during challenge tasks.

Exposition to Unfamiliar Situations at 19 Months

When participants were approximately 19 months old ($M = 18.50, SD = .82$), mothers and children visited the laboratory again, and children were exposed to two unfamiliar situations. The first situation involved a female adult confederate dressed as a clown (i.e., social unfamiliarity), and the second involved an odd-looking noisy and mechanical robot (i.e., non-social unfamiliarity) (for more details on the procedure, see the Supplement). The systematic coding of behaviors and emotional reactivity was analogous to previous studies on behavioral inhibition (Garcia-Coll et al., 1984; Kochanska & Radke-Yarrow, 1992; Rubin et al., 1997). Specifically, six behavioral indices were coded for each situation: 1) time spent in physical proximity to the mother (number of seconds the child spent within two feet of the mother), 2) latency leaving the mother (number of seconds before the child left the mother, i.e., left the two-feet proximal zone),

3) latency approaching the stimulus (number of seconds before the child approached within two feet of the unfamiliar stimulus), 4) interaction with the stimulus (sum of occurrences where the child interacted directly or indirectly with the stimulus), 5) negative affect and 6) positive affect.

Observations were coded by two research assistants who went through a rigorous 3-week training prior to the codification. First, 6% of the sample was double-coded and inter-rater agreement was deemed satisfactory, based on predetermined criteria (correlations for observations of behavior above .90 and kappa coefficients for the ratings of emotional reactions for both positive and negative affect above .80). To ensure independent and unbiased coding, each twin of a pair was coded by a different coder who were kept blind regarding the zygosity status of the twin. Throughout coding, inter-rater agreement was monitored once a week using the same predetermined criteria. In total, 10% of the sample was double-coded.

Sub-Dimensions of Behavioral Inhibition. Given prior work suggesting the multidimensional nature of the behavioral reactions to unfamiliarity (Kochanska & Radke-Yarrow, 1992; Putnam & Stifter, 2005), the twelve behavioral scores (six for each situation) were submitted to a principal component factor analysis using IBM SPSS Statistics (Version 26). As described in the Supplement and presented in Table S1, three factor components were identified: 1) avoidance of the robot, representing inhibition to non-social unfamiliarity (e.g., loading for *latency approaching the robot* = .88; loading for *interaction with the robot* = -.84), 2) avoidance of the clown, representing inhibition to social unfamiliarity (e.g., loading for *time spent in proximity to the mother during the clown situation* = -.86; loading for *latency leaving the mother during the clown situation* = -.84; since these loadings were negative, factor scores for avoidance of the clown were reversed), and 3) affect, representing both positive and negative

emotional reactions across both clown and robot situations (positive affect scores indicated positive emotional reactions and vice versa for negative scores). Factor scores were computed and considered in the following analyses. Avoidance of the robot was weakly correlated with avoidance of the clown ($r = .22, p < .05$), as well as negatively correlated with affect ($r = -.26, p < .05$). Avoidance of the clown was marginally correlated with affect ($r = -.09, p = .051$).

Assessment of Cortisol Response. Saliva sampling is a noninvasive way to reliably assess cortisol activity in basal and stressful contexts. Saliva samples were collected before and 20 minutes after the clown and robot situations to assess cortisol response. The procedure has been described elsewhere (see Ouellet-Morin et al., 2008).

Assessment of Social Wariness and Preference for Solitude at 4 and 5 Years Old

Social wariness and preference for solitude were assessed through mother ratings when the participants were aged 4 and 5 years. Mothers were asked to answer questions on a 0-to-2 scale (0 = *never*, 1 = *sometimes*, or 2 = *often*), starting with *Over the past 12 months, at which frequency would you say that your child....* The questions for social wariness were: 1) *was too fearful or anxious*, 2) *was worried*, 3) *was nervous or tense*, 4) *was shy with children that he or she did not know*, 5) *easily approached children that he or she did not know* (reversed), 6) *took a lot of time to get used to the presence of children that he or she did not know*. These items were adapted from Asendorpf's scale of situational shyness among unfamiliar peers (Asendorpf, 1987) and Achenbach's Teacher Report Form (Achenbach, 1991). To evaluate preference for solitude, questions to the mother were adapted from the Teacher Report Form (Achenbach, 1991) and from the Child Behavior Scale (Ladd & Profilet, 1996) and were: 1) *preferred to play alone rather than with other children*, 2) *tended to do things on his or her own, was rather solitary*, 3)

sought the company of other children (reversed). Internal consistency was evaluated using ordinal alpha and was satisfactory for both social wariness and preference for solitude at 4 ($\alpha = .79, .66$, respectively) and 5 years old ($\alpha = .78, .68$, respectively). At each assessment, items were averaged to compute final scores. Mother-rated social wariness scores at 4 and 5 years old were moderately correlated ($r = .51, p < .01$), and the same was found for preference for solitude ($r = .50, p < .01$).

Assessment of Social Wariness and Preference for Solitude at 6, 7 and 10 Years Old

In school, social wariness and preference for solitude were assessed through a combination of teacher ratings and peer nominations when participants were 6 (kindergarten), 7 (first grade) and 10 years old (fourth grade). For social wariness, teachers were asked to rate the participants' behavior over the past six months according to the same 0-to-2 scale and items used by the mothers at 4 and 5 years old, with an additional item, *avoided the company of other children*. For preference for solitude, teachers were asked similar questions as those used by mothers, plus an additional question: *demonstrated little interest in activities with other children*. Ordinal alpha for teacher measures of social wariness and preference for solitude were satisfactory at 6 ($\alpha = .83, .82$, respectively), 7 ($\alpha = .82, .80$, respectively) and 10 ($\alpha = .81, .81$, respectively) years old. Item scores for social wariness and preference for solitude at 6, 7 and 10 years old were averaged and then z-standardized. Correlations across teacher-rated social wariness at 6, 7 and 10 years old were mostly moderate ($r = .13$ to $.26, p < .01$), and the same was found for preference for solitude ($r = .21$ to $.28, p < .01$).

At 6 and 7 years old, children in the classroom were asked to nominate from a roster of photos two classmates who were the shyest (for more information on the peer nomination

procedure, see Boivin et al., 2013), whereas at 10 years old, peers had to choose two classmates who 1) were the shyest, 2) were the most fearful and 3) worried all the time. The number of nominations received at age 10 years for the three items were moderately to strongly correlated ($r = .27-.54, p < .01$) and were averaged to create a social wariness peer nomination score. As for preference for solitude at 6, 7 and 10 years old, children had to nominate two classmates who preferred to play by themselves. These peer nominations at 6, 7 and 10 years old were then z-standardized to adjust for classroom size (as participants in larger classrooms may receive more peer nominations). Peer-rated social wariness at 6, 7 and 10 years old were moderately correlated ($r = .19-.28, p < .01$). The correlation for preference for solitude between age 6 and 7 years ($r = .13, p < .01$), and between 7 and 10 years ($r = .10, p = .01$) were modest but significant. Then, standardized teacher and peer ratings were averaged to create composite social wariness and preference for solitude scores at ages 6, 7 and 10 years. Both of these social wariness and preference for solitude composite scores were moderately stable across time : $r = .22$ to $.36, p < .01$, and $r = .21$ to $.26, p < .01$, respectively. These composite teacher and peers scores were retained in the main analyses.

Estimation of Latent Variables for Social Wariness and Preference for Solitude

Social wariness and preference for solitude scores were then used to estimate latent variables using structural equation modeling. Latent variables typically reduce measurement error and yields more precise evaluations of constructs, especially if based on repeated assessments over time. Here, mother ratings of social wariness and preference for solitude were moderately correlated at 4 and 5 years old (r for social wariness = $.51$; r for preference for solitude = $.50$). Accordingly, we estimated one latent variable for social wariness in preschool

and one for preference for solitude. Similarly, composite scores of social wariness and preference for solitude at 6, 7 and 10 years old were weakly to moderately correlated (r for social wariness = .13 - .26; r for preference for solitude = .19-.28). Therefore, social wariness scores at 6, 7 and 10 years old were used to estimate a latent variable in grade school and the same was done for preference for solitude. Latent variables for preschool and grade school were included in the models to examine potential changes in predictive associations and to account for temporal stability across the two developmental periods.

Variable Transformations

The distributions of scores revealed significant outliers ($<$ or $>$ 3 SD from average) for cortisol and affect at age 19 months, as well as for both social wariness and preference for solitude at 6, 7 and 10 years old. To minimize potential biases from outliers, these distributions were winsorized to the last observed value before a 3-SD cutoff. This transformation improved the skewness for both social wariness and preference for solitude variables. As the distribution of cortisol response was still skewed, we performed an additional log-based transformation, which improved the distribution. In addition, as noted in overall skewed distributions, few children rapidly approached the clown (i.e., social inhibition) or the robot (i.e., non-social inhibition). No improvement in these distributions was noticed after a log-based transformation. Since neither distribution for social and non-social inhibition had outliers, we kept these variables untransformed, and, rather, dealt with non-normal distributions by using a robust maximum likelihood estimator in Mplus. Distributions of the final variables are presented in Figure S1.

Statistical Analyses

Descriptive Analyses

Descriptive analyses were conducted in IBM SPSS Statistics (Version 26). Variables' mean and standard deviation along with the number of participants for each variable are presented in Table 1. To account for sex differences in preference for solitude at age 6, 7 and 10 years (girls had significantly lower scores than boys) and in social wariness at age 10 years (girls had significantly higher scores than boys), these variables were regressed on sex in the structural equation models (independent samples t-tests to examine sex differences are presented in the Supplement).

Sequential Models Predicting Social Wariness and Preference for Solitude

We then ran multiple sequential structural equation models to examine pathways through which early behavioral inhibition, affect and cortisol response predicted social wariness and preference for solitude, and the extent to which vagal suppression moderated these associations. Models were sequential in that they considered predicting preschool social wariness and preference for solitude, and then the same outcomes in grade school. Models were first estimated with robust maximum likelihood (MLR) in Mplus 8.2 to handle missing data, non-normal distributions of variables and dependency of twin data (Muthén & Muthén, 1998-2017). Models were then estimated by bootstrapping one thousand times to obtain confidence intervals of indirect paths. Participants with at least one available data were included in the models (N = 1199).

Sequential models were tested in two steps. First, we examined how putative antecedents (i.e., social and non-social inhibition, affect, cortisol response and vagal suppression) predicted dimensions of social withdrawal in preschool and grade school. All antecedent variables were considered as a block to examine their unique contributions. Both linear and non-linear relations

were tested by including the main effect of the z-standardized variable and its squared product. Non-linear relations were examined to test whether the associations differed at the ends of the distribution (e.g., highly disinhibited versus highly inhibited; blunted versus excessive cortisol response).

Second, we examined whether vagal suppression at 5 months moderated these associations. Interaction terms were computed using z-standardized variables. In the case of a significant non-linear relations, the interaction term was computed using the squared product (e.g., social inhibition² X vagal suppression), as non-linear effects best reflected the associations at play. Again, all precursors and their interactions with vagal suppression were entered together to examine their unique contributions.

In addition, the following parameters were included in all sequential models. First, the model included correlations between early predictors to account for their interrelatedness. Second, the model accounted for the phenotypic overlap between social wariness and preference for solitude by including 1) concurrent correlations between these constructs at 4, 5, 6, 7 and 10 years old and 2) correlations between the latent constructs during the preschool and grade school years. Third, we considered the stability in both social wariness and preference for solitude over time by including regressive paths from the preschool to the grade school years for each latent variable of social wariness and preference for solitude. Fourth, the model accounted for sex differences in social wariness at age 10 years and in preference for solitude at ages 6, 7 and 10 years by regressing these variables on sex. Fifth, the model accounted for other confounding sociodemographic and parenting factors by regressing all variables on both parents' education level, first language spoken, ethnicity, age at child's birth, overprotective parenting behaviors

when children were 30 months old, family income and family status (i.e., single-parent versus two-parent families).

Sensitivity Analyses

To examine whether results were affected by the lower number of participants assessed at 5 and 19 months, we compared the baseline and complete models (without covariates, to simplify models) using only the participants for whom data was collected at either 5 or 19 months ($N = 564$). Results were analogous to models including participants who had at least one available data ($N = 1199$). Path estimates and model fit indices were comparable. We thus present the findings drawn from all available data to maximize statistical power and representativeness.

At each step, we also ran models including only grade school latent variables to examine whether early precursors were directly associated with social wariness and preference for solitude during the grade school years. Findings were analogous to those of the models including preschool variables, suggesting that accounting for the stability across the two developmental periods did not significantly impact the results.

Results

Baseline Sequential Model Predicting Social Wariness and Preference for Solitude

The baseline sequential model with standardized path estimates is presented in Figure 1. The model is sequential in that it accounts for the temporal stability for both social wariness and preference for solitude from the preschool and to the grade school years. The model included 1199 participants and had a good fit: Root Mean Square Error of Approximation (RMSEA) = .02

(90% confidence intervals [CI] = .00-.02); Comparative Fit Index (CFI) = .99; Tucker Lewis Index (TLI) = .93.

Predicting Preschool Social Wariness and Preference for Solitude

As shown in the baseline model, social inhibition was non-linearly (i.e., quadratic) associated with both preschool social wariness ($\beta = .20, p = .03$) and preference for solitude ($\beta = .25, p = .003$; see Figure 1 and 2), with the association mostly driven by the high end of the distribution. Regarding social wariness, children who displayed high social inhibition (1 SD above average) were more likely to show higher social wariness later in preschool than other children (see the variable's distribution in Figure S1). Regarding preference for solitude, both disinhibited (i.e., children who quickly approached the clown) and inhibited children showed higher levels of preference for solitude than children displaying average inhibition. In sum, these results indicate that social inhibition independently and differentially predicts social wariness and preference for solitude and that these associations are non-linear.

Predicting Grade School Social Wariness and Preference for Solitude

As shown in Figure 1, both preschool social wariness ($\beta = .42, p < .001$) and preference for solitude ($\beta = .28, p < .001$) were moderately stable over time. After taking this stability into account, only non-social inhibition added to the later prediction of social wariness in grade school ($\beta = .16, p = .05$). Another significant, but marginal indirect path was found after the bootstrapping analyses, with high social inhibition (the squared product variable) predicting grade school preference for solitude via preschool preference for solitude ($\beta = .02$; 95% CI = .003, .03). No other indirect path to dimensions of social withdrawal during the grade school years was found.

Interactions with Vagal Suppression

Then, we tested a model including all predictors from the baseline model (social and non-social inhibition, affect, cortisol response) and their respective interactions with vagal suppression (e.g., affect X vagal suppression) (see Figure S2). Since social inhibition was non-linearly predictive of both preschool dimensions, the interaction term was computed using the squared product of the variable for social inhibition (i.e., social inhibition² X vagal suppression).

Predicting Preschool Social Wariness and Preference for Solitude

Vagal suppression interacted with affect in predicting preschool preference for solitude ($\beta = -.14, p = .02$). Negative affect (as reflected by negative scores on the affect component) predicted higher preschool preference for solitude, but only when vagal suppression was low (see Figure 3). No other interaction with vagal suppression significantly predicted social wariness or preference for solitude in preschool.

Predicting Grade School Social Wariness and Preference for Solitude

Vagal suppression moderated the link between cortisol response and grade school social wariness ($\beta = -.17, p = .03$), that is, above and beyond preschool social wariness (see Figure 4). However, vagal suppression differentially increased the risk of manifesting social wariness at high and low levels of cortisol response. A strong cortisol response was associated with higher social wariness when vagal suppression was higher. Further, a weak cortisol response was associated with higher social wariness when vagal suppression was lower.

Discussion

The goal of the present study was to examine 1) the ways in which early behavioral inhibition towards social or non-social unfamiliarity, including the affective and cortisol responses, predicted specific dimensions of social withdrawal (i.e., social wariness, preference for solitude) in preschool and in grade school, and 2) whether these predictive associations varied depending on vagal suppression. Overall, the present study showed that early temperamental and biological vulnerabilities assessed during the first two years of life independently predicted the long-term development of social wariness and preference for solitude in childhood, and that vagal suppression did not play the same role in modulating the risk associated with each dimension of social withdrawal.

First, findings showed that inhibition in situations of social unfamiliarity at 19 months (i.e., social inhibition) independently predicted social wariness and preference for solitude years later. Specifically, children who never approached the unfamiliar clown in the laboratory (i.e., who were highly inhibited) were more likely to manifest social wariness and preference for solitude during the preschool years. Second, we found that children's vagal suppression at 5 months moderated the link between affect and preference for solitude. Negative affect in unfamiliar situations at 19 months was associated with higher preference for solitude during the preschool years at low levels of vagal suppression. Third, vagal suppression at 5 months also increased the risk of developing social wariness during the grade school years, but differentially at high and low levels of cortisol response at 19 months. Children who had a *strong* cortisol response showed higher social wariness at *high* levels of vagal suppression, while children who had a *low* cortisol response showed higher social wariness at *low* levels of vagal suppression. Finally, our findings showed that children who quickly approached the clown (i.e., who were disinhibited) were also more likely to develop a tendency to prefer solitude.

Previous studies have shown that behavioral inhibition in the first years of life is predictively associated with social withdrawal years later (Fox et al., 2005; Pérez-Edgar et al., 2011). Our findings extend these studies in two ways. First, results suggest that behavioral inhibition may represent a multidimensional construct, and that inhibition in social versus non-social unfamiliar situations as well as affect in reaction to unfamiliarity may constitute distinct aspects of temperament, which in turn, may uniquely predict dimensions of social withdrawal (Kochanska & Radke-Yarrow, 1992; Putnam & Stifter, 2005). Second, inhibition to social unfamiliarity independently predicted social wariness and preference for solitude, suggesting that subtypes of social withdrawal may have unique developmental pathways. Specifically, social inhibition non-linearly predicted social wariness and preference for solitude during the preschool years and these associations were robust to the different methods used (i.e., observation of social inhibition in experimental situations predicting mother ratings of subtypes of social withdrawal) and to the considerable time gap between both assessments (i.e., from 19 months to 4-5 years old).

The prediction of preschool social wariness and preference for solitude supports prior evidence suggesting that inhibition to social unfamiliarity forecast later social withdrawal (Dyson et al., 2011; Kochanska & Radke-Yarrow, 1992). Our findings suggest that this prediction is non-linear and unique to each dimension of social withdrawal, with children who were the most inhibited to the social unfamiliarity showing the highest levels of social wariness and preference for solitude during the preschool years. This finding supports prior studies suggesting that a temperamental profile characterized by complete avoidance unfamiliar people may be an early sign of later behavioral difficulties (Garcia-Coll et al., 1984). Thus, our results indicate that the consistent manifestation of inhibition at 19 months (i.e., never leaving the

proximity of the mother) independently predicts two subtypes of social withdrawal at 4-5 years old.

In addition, our study shows that vagal suppression at 5 months moderated the links between early temperamental (i.e., affect) and physiological (i.e., cortisol response) dispositions. First, vagal suppression interacted with affect in unfamiliar situations to predict preference for solitude in preschool. Children who manifested more negative affect in reaction to both social and non-social unfamiliarity showed higher preference for solitude if they previously showed low vagal suppression at 5 months. In contrast, high vagal suppression, which reflected a strong parasympathetic response in challenge situations, attenuated the risk associated with negative affect. This prediction from low vagal suppression combined with negative affect to preference for solitude could be explained by behavioral and peer problems. Studies have showed that a combination of negative affect (or low positive affect) and low self-regulation predicts comorbid internalizing and externalizing difficulties, which, in turn, are related to negative peer experiences (Arseneault et al., 2010; Nigg, 2006). As negative peer experiences have been shown to increase children's tendency to prefer solitude, (Ladd et al., 2019), this could be one developmental pathway through which the combination of low vagal suppression and negative affect predicts preference for solitude.

Further, we found that vagal suppression interacted with cortisol response to predict social wariness during the grade school years, over and above previous levels in preschool. Grade school is a stressful period for socially wary children, who often face increased social demands, including peer pressure to interact socially and teachers' expectations for students to develop social competencies (Rubin et al., 2009). Thus, during this period, children who are

physiologically vulnerable to stress may cope by withdrawing in the presence of unfamiliar peers to avoid being uncomfortable in these situations. Here, children who showed a strong cortisol response to unfamiliarity at 19 months manifested higher social wariness in grade school at higher levels of vagal suppression. This finding is in line with the proposition that internalizing difficulties are associated with excessive physiological responses in situations of stress (Beauchaine, 2001). Indeed, higher vagal suppression has been observed in children who display internalizing difficulties following exposure to environmental adversity (Gazelle & Druhen, 2009; Gray et al., 2017). In stressful situations, a combination of high cortisol response and excessive vagal suppression may reflect a hypervigilance typical of anxious individuals and thus lead to the development of social wariness in potentially threatening social situations, here represented by encounters with unfamiliar peers (Henderson et al., 2004).

On the other hand, this interaction also showed that a combination of low cortisol response and low vagal suppression predicted higher social wariness. Prior evidence shows that individuals with elevated or comorbid forms of anxiety, particularly those who previously experienced severe adversity, often show blunted cortisol response in stressful situations (Van Der Vegt et al., 2010). The absence of cortisol response in moderately stressful situations is thought to reflect dysregulated HPA axis activity and thus an impaired ability to adapt, possibly due to chronic allostatic load (Juster et al., 2010). Combined with poor vagal suppression, a blunted cortisol response may signal a physiological vulnerability to stress, which could lead to the manifestation of social wariness. Overall, the interaction between cortisol response and vagal suppression highlights the complexity of the interrelatedness between both physiological systems, as the role of vagal suppression in increasing risk for social wariness appears to be different depending on the level of cortisol response.

Finally, our results indicate that preference for solitude was linked to disinhibition in contexts of social unfamiliarity. One pathway by which disinhibition could lead to preference for solitude is, again, through increased risk for negative peer experiences (Ladd et al., 2019). Disinhibition and self-regulation difficulties have been associated with higher risk of externalizing problems in childhood, which, in turn, increase the risk of experiencing peer problems (Arseneault et al., 2010; Hirshfeld-Becker et al., 2003). Since repeatedly experiencing peer difficulties has been associated with an increased tendency to prefer solitary activities (Ladd et al., 2019), early disinhibition may lead to preference for solitude via externalizing and peer problems. Future longitudinal studies should examine whether this developmental pathway constitutes a mediating mechanism for the long-term association between early disinhibition and the tendency to prefer for solitude in childhood.

Strengths and Limitations

The present study extends previous research in several ways. The few longitudinal studies on the early temperamental and biological precursors of social withdrawal and their respective interactions with vagal suppression were either limited in sample size, conducted over short periods of time, or did not compare specific dimensions of social withdrawal. Our study addressed this limit by using data from a large population-based longitudinal study and by covering a 10-year period, thereby offering a broader window into the etiological pathways underlying dimensions of social withdrawal. It is the first study to test the predictive value of temperamental and biological dispositions on specific dimensions of social withdrawal from early childhood to grade school. Further, we collected measures through different approaches (biological samples, observation, reports) and from different informants (research assistants,

mothers, teachers, peers), which increased the validity and reliability of assessments and decreased measurement error and bias from shared method variance.

Still, these findings must be interpreted while considering some limitations. First, although children included in the sample were representative of the population in the greater Montréal area in the mid 1990s, most of them were White and spoke French (the language most spoken in Québec). Thus, results can hardly be generalized to other groups, for instance, migrant children or children from diverse cultural, ethnic and linguistic backgrounds. Second, the assessment of social inhibition, non-social inhibition and affect in unfamiliar situations in an artificial laboratory setting may have reduced the possibility to generalize findings to other contexts. For instance, exposition to social unfamiliarity was evaluated by placing the child in a room with an unfamiliar adult dressed as a clown. Consequently, this experimental context may not generalize to real-life settings including adult strangers. Similarly, as we did not assess social inhibition with same-age peers at 19 months, we cannot conclude that participants would have reacted similarly if they met unfamiliar peers. Third, even if reliability indices suggested a good convergence between items, better assessments may have been obtained by using validated scales measuring dimensions of social withdrawal (e.g., Child Social Preference Scale; Coplan et al., 2013). Fourth, since the present longitudinal study was conducted prior to recent theoretical and empirical advances on the different motives for preference for solitude (i.e., unsociability versus social avoidance), the study did not attempt to identify specific forms of preference for solitude (Coplan et al., 2013). Finally, we cannot exclude the possibility that the significant association between social inhibition and mother-rated social wariness and preference for solitude at 4 and 5 years old may be partly attributed to characteristics of the methodology. Mothers were also present during the exposition to unfamiliarity at 19 months. Thus, mothers'

perception of their child's behavior at 4 and 5 years old could have been affected by their previous experience at the laboratory.

Conclusion

The present study contributes to extend current knowledge on the early temperamental and biological dispositions linked to dimensions of social withdrawal. Overall, results contribute to clarify the distinctions between the risk of developing social wariness and preference for solitude. In conclusion, the study underscores the necessity of considering both early behavioral and biological dispositions as well as indicators of physiological regulation to provide a broader and more complete window into the developmental pathways to social withdrawal.

References

- Achenbach, T. M. (1991). *Manual for the child behavior checklist/4-18 and 1991 profile*.
University of Vermont, Department of Psychiatry
- Arseneault, L., Bowes, L., & Shakoor, S. (2010). Bullying victimization in youths and mental health problems: ‘Much ado about nothing’? *Psychological Medicine*, 40(5), 717-729.
<https://doi.org/10.1017/S0033291709991383>
- Asendorpf, J. B. (1987). Social competence. In F. E. Weinert & W. Schneider (Eds.), *LOGIC - Report No. 2: Assessment procedures used in waves ones to three*. Max-Planck Institut für psychologische Forschung.
- Beauchaine, T. P. (2001). Vagal tone, development, and Gray’s motivational theory: Toward an integrated model of autonomic nervous system functioning in psychopathology.
Development and Psychopathology, 13(2), 183–214.
<https://doi.org/10.1017/S0954579401002012>
- Blair, C., Peters, R., & Granger, D. (2004). Physiological and neuropsychological correlates of approach/withdrawal tendencies in preschool: Further examination of the behavioral inhibition system/behavioral activation system scales for young children. *Developmental Psychobiology*, 45(3), 113–124. <https://doi.org/10.1002/dev.20022>
- Boivin, M., Brendgen, M., Dionne, G., Ouellet-Morin, I., Dubois, L., Périusse, D., Robaey, P., Tremblay, R. E., & Vitaro, F. (2019). The Quebec Newborn Twin Study at 21. *Twin Research and Human Genetics*, 22(6), 475–481. <https://doi.org/10.1017/thg.2019.74>
- Boivin, M., Brendgen, M., Vitaro, F., Dionne, G., Girard, A., Périusse, D., & Tremblay, R. E.

- (2013). Strong genetic contribution to peer relationship difficulties at school entry: Findings from a longitudinal twin study. *Child Development*, 84(3), 1098–1114.
<https://doi.org/10.1111/cdev.12019>
- Buss, K. A., Davis, E. L., Ram, N., & Coccia, M. (2018). Dysregulated fear, social inhibition, and respiratory sinus arrhythmia: A replication and extension. *Child Development*, 89(3), e214–e228. <https://doi.org/10.1111/cdev.12774>
- Calkins, S. D., Graziano, P. A., & Keane, S. P. (2007). Cardiac vagal regulation differentiates among children at risk for behavior problems. *Biological Psychology*, 74(2), 144–153.
<https://doi.org/10.1016/j.biopsycho.2006.09.005>
- Coplan, R. J., Girardi, A., Findlay, L. C., & Frohlick, S. L. (2007). Understanding solitude: Young children's attitudes and responses toward hypothetical socially withdrawn peers. *Social Development*, 16(3), 390–409. <https://doi.org/10.1111/j.1467-9507.2007.00390.x>
- Coplan, R. J., Rose-Krasnor, L., Weeks, M., Kingsbury, A., Kingsbury, M., & Bullock, A. (2013). Alone is a crowd: Social motivations, social withdrawal, and socioemotional functioning in later childhood. *Developmental Psychology*, 49(5), 861–875.
<https://doi.org/10.1037/a0028861>
- Davis, E. L., & Buss, K. A. (2012). Moderators of the relation between shyness and behavior with peers: Cortisol dysregulation and maternal emotion socialization. *Social Development*, 21(4), 801–820. <https://doi.org/10.1111/j.1467-9507.2011.00654.x>
- Degnan, K. A., & Fox, N. A. (2007). Behavioral inhibition and anxiety disorders: Multiple levels of a resilience process. *Development and Psychopathology*, 19(3), 729–746.
<https://doi.org/10.1017/S0954579407000363>

- Degnan, K. A., Henderson, H. A., Fox, N. A., & Rubin, K. H. (2008). Predicting social wariness in middle childhood: The moderating roles of childcare history, maternal personality and maternal behavior. *Social Development, 17*(3), 471–487. <https://doi.org/10.1111/j.1467-9507.2007.00437.x>
- Dyson, M. W., Klein, D. N., Olino, T. M., Dougherty, L. R., & Durbin, C. E. (2011). Social and non-social behavioral inhibition in preschool-age children: Differential associations with parent-reports of temperament and anxiety. *Child Psychiatry and Human Development, 42*(4), 390–405. <https://doi.org/10.1007/s10578-011-0225-6>
- Fox, N. A., Henderson, H. A., Marshall, P. J., Nichols, K. E., & Ghera, M. M. (2005). Behavioral inhibition: Linking biology and behavior within a developmental framework. *Annual Review of Psychology, 56*(1), 235–262. <https://doi.org/10.1146/annurev.psych.55.090902.141532>
- Garcia-Coll, C., Kagan, J., & Reznick, J. S. (1984). Behavioral inhibition in young children. *Child Development, 55*(3), 1005–1019.
- Gazelle, H., & Druhen, M. J. (2009). Anxious solitude and peer exclusion predict social helplessness, upset affect, and vagal regulation in response to behavioral rejection by a friend. *Developmental Psychology, 45*(4), 1077–1096. <https://doi.org/10.1037/a0016165>
- Gray, S. A. O., Theall, K., Lipschutz, R., & Drury, S. (2017). Sex differences in the contribution of respiratory sinus arrhythmia and trauma to children’s psychopathology. *Journal of Psychopathology and Behavioral Assessment, 39*(1), 67–78. <https://doi.org/10.1007/s10862-016-9568-4>
- Graziano, P. A., & Derefinko, K. (2013). Cardiac vagal control and children’s adaptive

functioning: A meta-analysis. *Biological Psychology*, 94(1), 22–37.

<https://doi.org/10.1016/j.biopsycho.2013.04.011>

Graziano, P. A., Keane, S. P., & Calkins, S. D. (2007). Cardiac vagal regulation and early peer status. *Child Development*, 78(1), 264–278. <https://doi.org/10.1111/j.1467-8624.2007.00996.x>

Gunnar, M. R., Tout, K., de Haan, M., Pierce, S., & Stansbury, K. (1997). Temperament, social competence, and adrenocortical activity in preschoolers. *Developmental Psychobiology*, 31(1), 65–85.

Hastings, P. D., Kahle, S., & Nuselovici, J. M. (2014). How well socially wary preschoolers fare over time depends on their parasympathetic regulation and socialization. *Child Development*, 85(4), 1586–1600. <https://doi.org/10.1111/cdev.12228>

Hastings, P. D., Sullivan, C., McShane, K. E., Coplan, R. J., Utendale, W. T., & Vyncke, J. D. (2008). Parental socialization, vagal regulation, and preschoolers' anxious difficulties: Direct mothers and moderated fathers. *Child Development*, 79(1), 45–64. <https://doi.org/10.1111/j.1467-8624.2007.01110.x>

Henderson, H. A., Marshall, P. J., Fox, N. A., & Rubin, K. H. (2004). Psychophysiological and behavioral evidence for varying forms and functions of nonsocial behavior in preschoolers. *Child Development*, 75(1), 251–263. <https://doi.org/10.1111/j.1467-8624.2004.00667.x>

Hirshfeld-Becker, D. R., Biederman, J., Calltharp, S., Rosenbaum, E. D., Faraone, S. V., & Rosenbaum, J. F. (2003). Behavioral inhibition and disinhibition as hypothesized precursors to psychopathology: Implications for pediatric bipolar disorder. *Biological Psychiatry*, 53(11), 985–999. [https://doi.org/10.1016/S0006-3223\(03\)00316-0](https://doi.org/10.1016/S0006-3223(03)00316-0)

- Juster, R. P., McEwen, B. S., & Lupien, S. J. (2010). Allostatic load biomarkers of chronic stress and impact on health and cognition. *Neuroscience and Biobehavioral Reviews*, 35(1), 2–16. <https://doi.org/10.1016/j.neubiorev.2009.10.002>
- Kochanska, G., & Radke-Yarrow, M. (1992). Inhibition in toddlerhood and the dynamics of the child's interaction with an unfamiliar peer at age five. *Child Development*, 63(2), 325-335. <https://doi.org/10.2307/1131482>
- Ladd, G. W., Ettekal, I., & Kochenderfer-Ladd, B. (2019). Longitudinal changes in victimized youth's social anxiety and solitary behavior. *Journal of Abnormal Child Psychology*, 47(7), 1211–1223. <https://doi.org/10.1007/s10802-018-0467-x>
- Ladd, G. W., & Profilet, S. M. (1996). The Child Behavior Scale: A teacher-report measure of young children's aggressive, withdrawn, and prosocial behaviors. *Developmental Psychology*, 32(6), 1008–1024. <https://doi.org/10.1037/0012-1649.32.6.1008>
- Morneau-Vaillancourt, G., Matte-Gagné, C., Cheesman, R., Brendgen, M., Vitaro, F., Tremblay, R., Dionne, G., & Boivin, M. (2021). Social wariness, preference for solitude, and peer difficulties in middle childhood: A longitudinal family-informed study. *Developmental Psychology*, 57(3), 410–420. <https://doi.org/10.1037/dev0000961>
- Morneau-Vaillancourt, G., Andlauer, T. F. M., Ouellet-Morin, I., Paquin, S., Brendgen, M. R., Vitaro, F., Gouin, J., Séguin, J. R., Gagnon, É., Cheesman, R., Forget-Dubois, N., Rouleau, G. A., Turecki, G., Tremblay, R. E., Côté, S. M., Dionne, G., & Boivin, M. (2021). Polygenic scores differentially predict developmental trajectories of subtypes of social withdrawal in childhood. *Journal of Child Psychology and Psychiatry*, 62(11), 1320-1329. <https://doi.org/10.1111/jcpp.13459>

- Muthén, L. K., & Muthén, B. O. (1998-2017). *Mplus user's guide (8th ed.)*. Muthén & Muthén.
https://www.statmodel.com/download/usersguide/MplusUserGuideVer_8.pdf
- Nigg, J. T. (2006). Temperament and developmental psychopathology. *Journal of Child Psychology and Psychiatry and Allied Disciplines*, 47(3–4), 395–422.
<https://doi.org/10.1111/j.1469-7610.2006.01612.x>
- Ouellet-Morin, I., Boivin, M., Dionne, G., Lupien, S. J., Arsénault, L., Barr, R. G., Perusse, D., & Tremblay, R. E. (2008). Variations in heritability of cortisol reactivity to stress as a function of early familial adversity among 19-month-old twins. *Archives of General Psychiatry*, 65(2), 211. <https://doi.org/10.1001/archgenpsychiatry.2007.27>
- Pérez-Edgar, K., Reeb-Sutherland, B. C., McDermott, J. M., White, L. K., Henderson, H. A., Degnan, K. A., Hane, A. A., Pine, D. S., & Fox, N. A. (2011). Attention biases to threat link behavioral inhibition to social withdrawal over time in very young children. *Journal of Abnormal Child Psychology*, 39(6), 885–895. <https://doi.org/10.1007/s10802-011-9495-5>
- Poliakova, N., Dionne, G., Dubreuil, E., Ditto, B., Pihl, R. O., Périus, D., Tremblay, R. E., & Boivin, M. (2014). A methodological comparison of the Porges algorithm, fast Fourier transform, and autoregressive spectral analysis for the estimation of heart rate variability in 5-month-old infants. *Psychophysiology*, 51(6), 579–583. <https://doi.org/10.1111/psyp.12194>
- Porges, S. W. (2007). The polyvagal perspective. *Biological Psychology*, 74(2), 116–143.
<https://doi.org/10.1016/j.biopsycho.2006.06.009>
- Putnam, S. P., & Stifter, C. A. (2005). Behavioral approach-inhibition in toddlers: Prediction from infancy, positive and negative affective components, and relations with behavior problems. *Child Development*, 76(1), 212–226. <https://doi.org/10.1111/j.1467->

- Rubin, K. H., Coplan, R. J., & Bowker, J. C. (2009). Social withdrawal in childhood. *Annual Review of Psychology*, 60(1), 141–171.
<https://doi.org/10.1146/annurev.psych.60.110707.163642>
- Rubin, K. H., Hastings, P. D., Stewart, S. L., Henderson, H. A., & Chen, X. (1997). The consistency and concomitants of inhibition: Some of the children, all of the time. *Child Development*, 68(3), 467–483. <https://doi.org/10.2307/1131672>
- Schmidt, L. A., Fox, N. A., Rubin, K. H., Sternberg, E. M., Gold, P. W., Smith, C. C., & Schulkin, J. (1997). Behavioral and neuroendocrine responses in shy children. *Developmental Psychobiology*, 30(2), 127–140. [https://doi.org/10.1002/\(SICI\)1098-2302\(199703\)30:2<127::AID-DEV4>3.0.CO;2-S](https://doi.org/10.1002/(SICI)1098-2302(199703)30:2<127::AID-DEV4>3.0.CO;2-S)
- Smider, N. A., Essex, M. J., Kalin, N. H., Buss, K. A., Klein, M. H., Davidson, R. J., & Goldsmith, H. H. (2002). Salivary cortisol as a predictor of socioemotional adjustment during kindergarten: A prospective study. *Child Development*, 73(1), 75–92.
<https://doi.org/10.1111/1467-8624.00393>
- Smith, K. A., Hastings, P. D., Henderson, H. A., & Rubin, K. H. (2019). Multidimensional emotion regulation moderates the relation between behavioral inhibition at age 2 and social reticence with unfamiliar peers at age 4. *Journal of Abnormal Child Psychology*, 47(7), 1239–1251. <https://doi.org/10.1007/s10802-018-00509-y>
- Van Der Vegt, E. J. M., Van Der Ende, J., Huizink, A. C., Verhulst, F. C., & Tiemeier, H. (2010). Childhood adversity modifies the relationship between anxiety disorders and cortisol secretion. *Biological Psychiatry*, 68(11), 1048–1054.

Tables and Figures

Table 1

Descriptive Statistics

	Mean	SD	N
Vagal suppression 5 months old	-.56	.43	448
Non-social inhibition (robot situation) 19 months old	.04	.99	462
Social inhibition (clown situation) 19 months old	.01	.98	462
Affect (clown and robot situations) 19 months old	.05	.87	462
Cortisol response 19 months old	.29	1.00	437
Social wariness 4 years old (mother)	.64	.41	883
Social wariness 5 years old (mother)	.59	.39	882
Social wariness 6 years old (teacher and peers)	-.01	.80	780
Social wariness 7 years old (teacher and peers)	-.01	.78	790
Social wariness 10 years old (teacher and peers)	.01	.81	789
Preference for solitude 4 years old (teacher and peers)	.74	.45	882
Preference for solitude 5 years old (teacher and peers)	.67	.46	882
Preference for solitude 6 years old (teacher and peers)	-.01	.72	779
Preference for solitude 7 years old (teacher and peers)	-.01	.77	790
Preference for solitude 10 years old (teacher and peers)	-.04	.78	724

Figure 1

Baseline Sequential Model Predicting Social Wariness and Preference for Solitude

Note. * $p < .05$. [†] $p = .05$. Abbreviations: m = months old; yo = years old. Only significant paths and correlations are shown.

Figure 2

Non-Linear Predictive Associations from Social Inhibition to Dimensions of Social Withdrawal in Preschool in the Baseline Model

Figure 3

Vagal Suppression Interacts with Affect in Unfamiliar Situations to Predict Preschool Preference for Solitude in the Complete Sequential Model

Note. Negative affect scores represent negative affect and positive scores represent positive affect.

Figure 4

Vagal Suppression Interacts with Cortisol Response in Unfamiliar Situations to Predict Grade School Social Wariness in the Complete Model