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Expressions of shyness and theory of mind in children: A psychophysiological study

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A B S T R A C T

This study examined relations among expressions of state shyness, Theory of Mind (ToM), and resting respiratory sinus arrhythmia (RSA) in 78 typically developing four-year-old children (M_{age} = 54.59 months; 41 females). Expressions of positive and non-positive state shyness were coded from direct observations during a self-presentation task, ToM was assessed with validated vignette tasks, and resting RSA data were collected while children watched an emotionally neutral video. We found that ToM was positively related to expressions of positive shyness and inversely related to expressions of non-positive shyness, replicating previous work. These relations were qualified by an interaction between resting RSA and expressions of positive shyness when analyzed with respect to ToM, such that children with higher resting RSA and more expressions of positive shyness exhibited the most sophisticated ToM. As such, early ToM development may be facilitated by a combination of behavioral regulatory expressions and parasympathetic control.

1. Introduction

Theory of Mind (ToM) is a social-cognitive skill that involves understanding, predicting, and explaining the behaviors of others by inferring their mental states (Wellman, 1990; Wellman & Liu, 2004). Children's capacity to understand and approach other people as independent mental agents begins in infancy. At this stage, infants learn rudimentary mentalizing behaviors, such as intentional communication (i.e., pointing), from interacting with their parents and caregivers (Brooks & Meltzoff, 2015; Colonnesi, Rieffe, Koops, & Perucchini, 2008). By the preschool years, most children can express their ToM understanding explicitly, which allows for more complex reasoning about others' emotions, the cognitive capacity to engage in pretend play, and the emergence of deeper self-consciousness around others. Although other-inference tends to develop most rapidly in the preschool years, children continue to gain more sophisticated mentalizing abilities through middle childhood and into adolescence (Muris et al., 1999; Perner & Wimmer, 1985; Wellman & Liu, 2004).

False-belief vignette tasks are considered the gold standard of ToM assessment. More basic mentalizing tasks evaluate the child's ability to understand diverse desires and reconstruct their own past false beliefs. As ToM becomes more sophisticated, children can grasp more complex vignette stories, such as those involving first-order and second-order false belief understanding. This mature reasoning is commonly achieved around the age of 4–6 years in typically developing individuals (Wellman & Liu, 2004), with children

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across cultures generally following the same developmental sequence (e.g., Wellman et al., 2011a).

ToM is an important component of a child's socioemotional development, since it contributes to the formation and consolidation of lasting and meaningful relationships with peers and adults (Devine, White, Ensor, & Hughes, 2016; Longobardi, Spataro, & Rossi-Arnaud, 2016). Identifying individual differences in the development of this skill is important, since delayed ToM has been associated with hostile attributional biases (Choe, Lane, Grabell, & Olson, 2013), aggressive behavior (Song, Volling, Lane, & Wellman, 2016), internalizing problems (Banerjee & Henderson, 2001), and social deficits in some children (Happe, 1994). Some such individual differences that are worth exploring in the context of ToM include temperament, affect, and regulation. One particular theoretically relevant factor is shyness, since it is applicable to how often and how skillfully children engage in social interaction.

1.1. Trait shyness and expressions of state shyness

Shyness has been characterized as an anxious preoccupation with the self in real or imagined social situations (Cheek & Melchior, 1990), and can be conceptualized as both a state and a trait. *State shyness* is an emotional reaction that can occur when an individual is in a situation that elicits social stress, such as during a presentation or when encountering new people (Asendorpf, 1990; Lewis, 2001). State shyness can be seen as a context-specific reaction to pre-existing trait shyness (Poole & Schmidt, 2022). *Trait shyness*, in contrast, is a temperamental or dispositional wariness of social novelty that is modestly stable across time and situations (Coplan & Rubin, 2010; Kagan, Reznick, Snidman, Gibbons, & Johnson, 1988).

Some have argued that shyness represents a social ambivalence in which approach and avoidance motivations are experienced simultaneously and in conflict (Asendorpf, 1990; Coplan, Prakash, O'Neil, & Armer, 2004; Lewis, 2001). However, we know that not all shy children are alike (e.g., Poole, Tang, & Schmidt, 2018; Poole & Schmidt, 2020a; Schmidt & Fox, 1999; Schmidt & Poole, 2018), and not all shyness is expressed in the same way (Colonnesi, Napoleone, & Bogels, 2014; Colonnesi, Nikolić, de Vente, & Bogels, 2017; Poole & Schmidt, 2019). An emerging body of recent research has outlined the importance of examining heterogeneity in state shyness by studying facial expressions (Colonnesi et al., 2014, 2017; Nikolić, Colonnesi, de Vente, & Bogels, 2016; Poole & Schmidt, 2019). To do this, children's responses to social stimuli can be behaviorally coded during self-presentation tasks, in which the child experiences simulated social evaluation from others. Coding of facial expression can be then used to determine the degree to which approach or avoidance motivations are involved at a given time or in a particular individual (Colonnesi et al., 2014; Nikolić et al., 2016; Poole & Schmidt, 2019).

These procedures result in the measurement of positive and non-positive expressions of shyness. Positive expressions of shyness (PES; sometimes referred to as 'positive shyness' in the literature) are defined as positive facial expressions (i.e., smiling) in combination with a gaze and/or head aversion (Asendorpf, 1990; see also Colonnesi et al., 2014). This behavior is thought to express a tension between aversion and enjoyment, with a dominating motivation for approach (Reddy, 2005; Thompson & Calkins, 1996). The development of smiling is thought to be highly related to processes that concern physiological mechanisms of arousal. It has been argued that PES in early childhood, and even infancy, may exist to reduce arousal during social interaction while simultaneously engaging with another person by holding their interest and attention (Sroufe & Waters, 1976). As such, some argue that these expressions may have evolved as social appeasement signals that serve regulatory functions to reduce fear during social situations (Colonnesi et al., 2014), which are also evidenced physiologically by distinct patterns of frontal brain activity (Poole & Schmidt, 2020b; Schmidt & Poole, 2021). Due to the affiliative nature of PES, children who display them often are thought to learn more from social situations and develop higher self-esteem when interacting with others (Thompson & Calkins, 1996). Although PES are thought to be accompanied by some discomfort and nervousness toward social stimuli, the regulation of arousal in real time and the affiliative nature of the smile arguably results in a more adaptive expression of shyness (Colonnesi et al., 2014; Schmidt & Poole, 2019).

While PES appear to be adaptive, by regulating stress associated with social interaction (Colonnesi et al., 2014; Colonnesi, Nikolić, & Bögels, 2020; Poole & Schmidt, 2019; Schmidt & Poole, 2019, 2020), expressions of non-positive shyness (NPES; also referred to as 'negative shyness' within the literature) are considered to be more avoidant reactions to social evaluation. Expressions of non-positive shyness are defined as gaze and/or head aversions during a negative or neutral facial expression, which largely express fear and discomfort rather than pleasure (Asendorpf, 1989, 1990; Colonnesi et al., 2014; much of the past literature has only evaluated negative expressions of shyness, in which the gaze/head aversion occurs during a negative facial expression). These expressions have been related to social inhibition and social anxiety, and they are inversely linked to sociability (Colonnesi et al., 2014; Poole & Schmidt, 2019), suggesting that NPES are associated with less ability to cope with social demands (Colonnesi et al., 2014). Although PES and NPES are mutually exclusive constructs, individuals can express varying degrees of both positive and non-positive expressions of shyness within the same episode.

1.2. Shyness and theory of mind

Although state shyness has strong behavioral and physiological implications for the development of ToM, the predominant research focus within past literature has been the relation between trait shyness and false-belief understanding. A child's dispositional shyness can influence his or her social experiences, and thus social learning opportunities, which are vital to the development of social-cognitive abilities such as ToM (e.g., Astington & Baird, 2005). While it is reasonable to argue that trait shyness could lead to reticent behavior, impeding the acquisition of ToM by slowing the development of social cognitive understanding (De Rosnay, Fink, Begeer, Slaughter, & Peterson, 2014; Kokkinos, Kakarani, & Kolovou, 2016), the majority of existing literature has provided evidence that, in infancy and through the preschool years, trait shyness allows for a more observant and vigilant social style, resulting in higher ToM (LaBounty, Bosse, Savicki, King, & Eisenstat, 2017; Lane et al., 2013; Longobardi, Spataro, D'Alessandro, & Cerutti, 2017; Mink, Henning, & Aschersleben, 2014; Wellman et al., 2011b). Aside from work surrounding trait shyness and ToM, there is also evidence to suggest that shy children possess unique social-cognitive strengths, allowing for heightened detection of social threat (Brunet et al., 2009; Hassan et al., 2021; MacGowan, Mirabelli, Obhi, & Schmidt, 2021; LoBue & Perez-Edgar, 2014; MacGowan et al., 2021; Matsuda et al., 2013). Thus, trait shyness may support observation rather than direct interaction involving participation. In fact, shyness is, at times, empirically investigated through the assessment of children's preference to watch others rather than engage directly with peers (Asendorpf, 1990; Coplan et al., 2004). This tendency could grant children who experience high levels of trait shyness with a more encompassed view of social intercommunication. In particular, shy children may observe more social cues and responses, internalize more information, and reflect more often on the thoughts and feelings of others.

The most common explanation that has been used to interpret the positive relation between shyness and ToM stems from the ontogenetic development of temperament and social cognition. The Emotional Reactivity Hypothesis (ERH) states that the evolution of less socially reactive[1] temperaments (i.e., more inhibited and shy temperaments) tends to facilitate better social-cognitive understanding in animal species such as domesticated dogs (Hare & Tomasello, 2005). In the context of child development, many have argued that shyness may promote a less aggressive and more observant social style that benefits social awareness and social learning (Labounty et al., 2017; Lane et al., 2013; Wellman et al., 2011b). Detecting and responding appropriately to social signals requires that the individual processes his or her social surroundings without reacting strongly or with haste.

In line with this hypothesis, shy children tend to exhibit low gregariousness and high perceptual sensitivity in social contexts, and thus may have the potential to develop more sophisticated social cognitive understanding (Kiel & Buss, 2011; Pérez-Edgar et al., 2010, 2011). While low-shy children can be relatively uninhibited and directly participatory when engaging in social interaction, high levels of trait shyness are thought to result in less participation and more direct observation. This combination of characteristics presumably allows for enhanced information processing during social learning opportunities, contributing to the development of social cognitive abilities such as ToM.

While most studies on this topic have explored relations between trait shyness and ToM, relatively few have addressed how state shyness influences the development of this skill. Colonnesi et al. (2017) have recently found that, in a sample of 4-year-old children, expressions of non-positive shyness were negatively associated with scores from a basic battery of ToM tasks, while expressions of positive shyness were positively associated with scores from a more sophisticated battery. In addition, Banerjee and Henderson (2001) found that socially anxious children with high negative shy affect displayed poor social cognitive understanding of emotions, intentions, and beliefs.

Despite our current knowledge regarding the relation between shyness and ToM in early childhood, there is one relevant factor that has not been investigated in the context of these constructs: autonomic regulation. Assessing psychophysiological measures of regulation and arousal alongside the relation between shyness and ToM may provide a deeper context for this association and help clarify prior inconsistent findings on this topic.

1.3. Parasympathetic control, shyness, and theory of mind

Given that expressions of positive shyness are hypothesized to be regulatory in the context of reducing children's social apprehension and fear (e.g., Sroufe & Waters, 1976), surprisingly few studies have examined measures of physiological regulation in relation to state shyness. To thoroughly investigate the relation between shyness and ToM, it is important to consider children's propensity to regulate and control their emotional and physiological responses. There is an existing literature that outlines the beneficial impact of self-regulation and parasympathetic control on young children's social cognitive processes, such as empathy and prosocial behavior (Eisenberg, 2005; Eisenberg & Fabes, 1992; MacGowan & Schmidt, 2020, 2021b). As such, children's ability to process and modulate arousal is likely valuable in the realm of paying attention to, and learning from, social cues and interactions. Physiological measures of parasympathetic control are of particular interest when examining shyness correlates since shyness can often be accompanied by physiological symptoms of fear, anxiety, and dysregulation of the internal milieu (LoBue & Perez-Edgar, 2014; Schmidt, Fox, Schulkin, & Gold, 1999). Importantly, Lane et al. (2013) have reported that children who experience high social fear and high physiological reactivity (i.e., high salivary cortisol), tend to experience low ToM in the preschool years. This work suggests that physiological measures of arousal may provide an important context for the role of expressions of shyness in ToM development.

One physiological measure that has not been explored in relation to shyness and ToM is respiratory sinus arrhythmia (RSA). RSA is a measure of heart rate variability coordinated with the respiratory cycle (Porges, Doussard-Roosevelt, & Maiti, 1994). Resting RSA is commonly used as an index for parasympathetic control and modulation of physiological arousal (Kahle, Utendale, Widaman, & Hastings, 2018; Reid et al., 2018), and is known to predict self-regulatory behaviors (Graziano & Derefinko, 2013; Porges, 2007). Overall, resting RSA is thought to reflect a predisposition for self-regulation and threshold for arousal (Hastings et al., 2006; Porges & Byrne, 1992). Thus, relatively high resting RSA is presumed to reflect a better capacity for adaptable behavioral responding (Porges, 2007, 2011), while lower resting RSA is presumed to reflect a lower capacity for self-regulation (Beauchaine, 2001; Porges, 2011; Thayer et al., 2012). As such, children with relatively low resting RSA tend to develop poor attentional and inhibitory control, and experience problems surrounding emotion regulation (Blandon, Calkins, Keane, & O'Brien, 2008; Calkins & Keane, 2004; Mezzacappa, Kindlon, Saul, & Earls, 1998; Suess, Porges, & Plude, 1994).

[1] It is important to note that the term reactivity as is used within the context of this hypothesis refers to social reactivity, which is the tendency to respond to social stimuli strongly or with haste. This term does not refer to a lower threshold for social or non-social sourced arousal, as it has been defined elsewhere previously (e.g., Rothbart & Bates, 2006).

Resting RSA has been previously explored as a moderator of risk (El-Sheikh, Harger, & Whitson, 2001; Khurshid, Peng, & Wang, 2019; Morales, Beekman, Blandon, Stifter, & Buss, 2015), and more specifically, as a moderator between shyness and various child outcomes. For example, Sulik et al. (2013) have reported that typically developing preschoolers who display low RSA and high shyness tend to exhibit the lowest effortful control. In addition, Hastings, Kahle, and Nuselovici (2014) found that baseline RSA moderated the relation between preschool social wariness and anxiety in middle childhood, such that children with relatively high RSA, but not low RSA, exhibited a negative relation between social wariness and later anxiety.

It can be argued that children with relatively high baseline RSA, who are presumed to possess higher parasympathetic control at rest, have more adaptive and flexible responses to social contexts in which they are required to focus on others. As well, some empirical evidence suggests that RSA tends to be particularly relevant when children are experiencing fear (Buss & Goldsmith, 2007). As such, this factor may be important to explore in the context of PES, NPES, and relevant correlates of shy expressions. In particular, considering parasympathetic control (i.e., RSA), behavioral regulation (i.e., state shyness), and their combination may offer a better understanding of children's ability to approach, observe, and learn from social situations, and as a result, develop the ability to attribute and understand false belief.

1.4. The present study

We sought to extend past findings by assessing whether baseline RSA, a proxy for physiological self-regulation and threshold for arousal, interacted with expressions of state shyness when analyzed with respect to ToM in early childhood. We expected that considering multiple levels of self-regulatory control (i.e., physiological and behavioral) would provide a more comprehensive context for the development of children's ability to approach, observe, and understand social situations, and therefore develop a sophisticated ToM understanding. We explored these relations in a sample of 78 typically developing 4-year-old children. We chose this age group due to the developmental relevance for the emergence of false belief understanding and the acceleration at which ToM develops within this year of life. We expected that while some children at this age would exhibit standard attribution of others' states, some would display advanced, or slightly delayed understanding, allowing for conservative inferences to be made about the effect of shyness on the development of this ability.

Positive expressions of shyness (PES: gaze aversion with positive facial expression) and non-positive expressions of shyness (NPES: gaze aversion with neutral *or* negative facial expressions) were coded from a behavioral task that elicits social stress, in which children were asked to perform a spontaneous speech about their most recent birthday in front of a video camera. ToM was assessed with a battery of well-validated tasks drawn from previous studies (Baron-Cohen, Leslie, & Frith, 1985; Miller, 2013; Perner, Leekam, & Wimmer, 1987; Wellman & Liu, 2004). Resting RSA data were collected while children watched an emotionally neutral video for five minutes prior to beginning any other study procedures.

We addressed the following two questions: First, are individual differences in children's observed positive expressions of shyness (PES) and non-positive expressions of shyness (NPES) associated with their ToM? Second, does resting RSA interact with individual differences in children's observed PES and NPES when analyzed with respect to ToM?

We predicted that, as reported by Colonnesi et al. (2017), PES would be positively related to ToM, while NPES would be negatively associated with ToM. We also expected that resting RSA would interact with observed expressions of shyness (i.e., positive and non-positive) when analyzed with respect to ToM. Specifically, we predicted that relatively high PES combined with high resting RSA would result in the highest ToM, whereas other PES by RSA combinations would result in moderate ToM understanding. Similarly, we expected that children with low resting RSA and high NPES would possess the lowest ToM understanding, whereas other NPES by RSA combinations would result in moderate ToM.

2. Method

2.1. Participants

Seventy-eight typically developing 4-year-old children (M_{age} = 54.59 months, *SD* = 2.82; Range = 48.4–59.5 months; 41 females) and their biological mothers participated in the present study. Children were recruited from the McMaster Infant Database, which contains the contact information of healthy, full-term infants who were born at the McMaster University Medical Center, St. Josephs' Healthcare, or Joseph Brant Hospital in the Hamilton, Ontario area, and whose mothers consented at that time to be contacted for future developmental studies. Within the sample, 50 (78%) of the children were White, one (1.6%) was Black, one (1.6%) was Asian, one was Hispanic (1.6%), 6 (9.4%) were reported as mixed race, 2 (3.1%) were reported as another race, and 3 (4.7%) did not report their race. All children were fluent in English; however, four children spoke English as their second language. Among parents, 86% of mothers and 82% of fathers had some form of post-secondary education (i.e., college diploma, university degree, etc.). Mothers reported their combined family income (in Canadian dollars) on a scale from 1 to 7 (1 = below $15,000; 4 = $45,000-$60,000; 7 = over $100,000). The parents of thirty-four children (53.1%) had combined family incomes of more than $100,000 per year; nineteen (29.7%) had an income between $60,000 and $100,000 per year, and 11 (17.2%) families earned less than $60,000 per year.

2.2. Procedure

Informed and written consent were obtained prior to each child beginning the study. A series of tasks were then carried out by one female experimenter while the child's mother sat in a different room and observed the procedures on a closed-circuit TV (CCTV) monitor. Mothers reported demographic information and completed other study questionnaires at this time. All procedures were approved by the McMaster Research Ethics Board. Children and families were compensated with a $20 gift card for their participation.

2.3. Electrocardiogram (ECG) recording procedure and measure

2.3.1. ECG recording

Three ECG electrodes were placed on the child's back in the shape of an inverted triangle, and a respiration belt was fastened around the child's chest while the mother was present. Electrodes were placed on the child's back to avoid child distraction and/or tugging and removal. The electrodes and respiration belt were attached to a MindWare Mobile Impedance Cardiograph, Model 50-2303-00, which was placed in an age-appropriate backpack and worn by the child. The mobile unit detected R-waves at a sampling rate of 500 Hz and 24-bit ADC digitization. Resting RSA data were collected for five minutes while the child was seated and watched an emotionally neutral video clip: a 6-minute excerpt from the family-friendly film, *Finding Nemo*. This clip was selected to be age-appropriate and engaging but did not include any strong emotions from the characters or any important plot points that would likely elicit emotional arousal in the child. This clip has been used previously to assess baseline RSA (Hassan et al., 2018; MacGowan et al., 2021; MacGowan & Schmidt, 2020, 2021a, 2021b).

2.3.2. ECG data reduction and RSA quantification

Cardiac and respiratory data were analyzed using the Mindware HRV 3.1.1 software package (Mindware, Gahanna, OH, USA). Peaks were edited manually for erroneous or missing beats according to recommendations of Berntson and Stowell (1998). HRV high-frequency band settings were set from 0.24 to 1.04 Hz, which is recommended for young children (Porges, 2007). Although there is some debate in regard to the frequency range that is suitable for use with young children (e.g., Shader et al., 2017), the present band settings have been recommended by a number of pediatric psychophysiology studies (see Bar-Haim, Marshall, & Fox, 2000; Porges, 2007; Quigley & Stifter, 2006) as well as by MindWare, the supplier of the mobile ECG unit. Average RSA was estimated for each 1-minute epoch and averaged across 5 consecutive epochs of interest (Caccioppo et al., 1994). The entire analyzed sample had five consecutive 1-minute epochs of clean, artifact-free RSA data.

2.4. Theory of Mind (ToM) assessment

Children's ToM was assessed with six well-validated tasks that progressively increased in difficulty from first to last. These included the Knowledge Access, Unexpected Contents, and Real-Apparent Emotion tasks (Wellman & Liu, 2004), the Smarties task (Perner et al., 1987), the Sally-Ann first-order false belief task (Baron-Cohen et al., 1985), and a second-order false belief task (Miller, 2013). Although the Unexpected Contents task and the Smarties task both involve the child witnessing a box containing something unexpected, the Smarties task focuses on the child's ability to reconstruct their own past false beliefs, while Wellman and Liu's version requires that the child understand another character's false belief about the contents of the box. When scoring children on the second-order belief task, they were awarded one point for understanding the first-order question, and a second point for correctly answering the second-order question with a proper explanation for their understanding. Therefore, the overall score for each child had a potential maximum of seven points from six tasks. Two coders scored the children from video recordings and obtained strong inter-rater reliability for all tasks ($\kappa = 0.98$). Although these ToM tasks have been validated for use with 4-year-old children, a small subset of children ($n = 10$) were unable to comprehend one or more of the stories (i.e., could not correctly answer a comprehension question, even after they were corrected). These children were assumed to have poor understanding of the questions asked and were therefore removed from further analyses. These children did not differ from the remaining sample on scores of overall PES ($p = .132$), overall NPES ($p = .590$), baseline RSA ($p = .126$), income ($p = .741$), age ($p = .531$), or PVT ($p = .197$).

2.5. Picture Vocabulary Test (PVT)

The Picture Vocabulary Test (PVT) was administered from the National Institute of Health (NIH) Toolbox application on an Apple iPad (HealthMeasures, Evanston, IL, USA), and was used to assess receptive vocabulary. Scores from this task were used as a covariate in our analyses, due to the known association between language and ToM (see de Villiers & de Villiers, 2014). The PVT involves a series of audible words, which the child must match to a corresponding series of picture sets. This application generates age-corrected standard scores, with an average score of 100 and a standard deviation of 15 for the general population.

2.6. Birthday Speech Self-Presentation Task

The Birthday Speech Self-presentation task has been previously used to reliably elicit trait shyness (MacGowan & Schmidt, 2020, 2021a, 2021b; Schmidt et al., 1999; Theall-Honey & Schmidt, 2006) and different expressions of state shyness (Poole & Schmidt, 2019) in children as young as 4 years old (Rubin et al., 1995; Theall-Honey & Schmidt, 2006; see also Colonnesi et al., 2017, for a similar self-presentation task in front of a video camera used at this age). This task is known to put the participant in a situation that involves social exposure. By four years old, children have understood and expressed self-conscious emotions, such as embarrassment, in such situations for at least two years of their life (Lewis, 2001; Lewis, Sullivan, Stanger, & Weiss, 1989), suggesting that they are capable of comprehending and experiencing anxious self-preoccupation in response to social exposure. Importantly, behaviorally coded measures of temperamental shyness that have been derived from this task are consistent with mothers' reports of their children's shyness at this age (MacGowan & Schmidt, 2020, 2021a, 2021b), suggesting that this procedure is capable of eliciting the self-conscious preoccupation that is indicative of trait and state shyness in this age group.

In this task, the experimenter spontaneously instructed the child to give a short speech about their most recent birthday in front of a video camera. The child was not given time to prepare their speech and was informed that the video would be shown to other children of their age. This allowed for the measurement of state shyness as a reaction of social stress from both an imagined audience of peers as well as the immediate presence of the experimenter. Parents were not present for this procedure but observed from another room using CCTV.

Although children were prompted for a minimum of 60 s, they were allowed to speak for as long as they wished. The first 60 s of each child's speech was coded for observed PES and NPES. Five children stood in front of the video camera for less than 60 s (ranging from 20 to 42 s). Of these children, two asked to use the bathroom during the speech, and three expressed fear and therefore refused to stand in front of the camera. These children did not differ from the remaining sample in age ($p = .318$), income ($p = .335$), RSA score ($p = .496$), or ToM ($p = .891$), and thus were not removed from statistical analysis. We handled these varied times by controlling for the total duration of the speech in our regressions below. Four children were coded for more than 65 s (ranging from 66 to 75 s), due to their walking out of the camera's view for a period of time during their speech. However, we added the amount of time that they spent off screen to end of their speech to allow for the same amount of codeable episode as the rest of the children. Similarly, these four children did not differ from the remaining sample in age ($p = .966$), income ($p = .984$), RSA score ($p = .454$), or ToM ($p = .257$), and thus were not removed from analyses. The remaining 69 children had speeches that ranged between 60 and 65 s in length.

PES were operationalized as gaze aversions occurring at the time of a positive facial expression. NPES were measured by assessing shy behaviors expressed both negatively (i.e., gaze aversion during negative facial expression) and neutrally (i.e., gaze aversion during neutral facial expression). We used both frequency of gaze aversions as well as duration of gaze away from a social stimulus during each facial expression as an overall measure of PES and NPES.

2.6.1. *Behavioral coding*

Two behaviors (i.e., facial expressions and direction of gaze) were independently coded on Noldus' Observer 13.0 (Zimmerman, Bolhuis, Willemsen, Meyer, & Noldus, 2009) behavioral coding software to obtain continuous measures of positive, negative, and neutral expressions of shyness, based on a previous coding scheme used in multiple studies (Colonnesi et al., 2014, 2017; Nikolić et al., 2016). A subset of 23% of participants was scored by two coders and reliability was corrected for kappa max (Bakeman, Deckner, & Quera, 2005). Inter-rater reliability was established for positive ($\kappa = 0.96$), negative ($\kappa = 0.99$), and neutral ($\kappa = 0.97$) expressions of shyness, accounting for both frequency and duration of each.

2.6.1.1. Facial expression. Facial expression was coded as a continuous mutually exclusive state event where coders distinguished between the children's emotive expressions. A positive facial expression was coded when the corners of the mouth were curled up and/or when the cheeks were raised. A negative facial expression occurred when eyebrows were lowered, furrowed together, or if the outer edges of the brows were lowered with inner edges simultaneously being heightened. This expression was also coded if the outer corners of the mouth curled down. Neutral facial expression was coded when the child did not exhibit characteristics of positive or negative facial expression and when no emotion-relevant muscle activity was observed in the face.

2.6.1.2. Direction of gaze. The direction of children's gaze was coded as either to the "camera", "experimenter", or "elsewhere" as a continuous mutually exclusive state event. We considered the child to be engaging in social gaze when looking at the video camera or the experimenter. Looking elsewhere was considered non-social. Gaze aversions were defined as the sudden change of gaze from a social to a non-social stimulus as a result of apparent arousal. The coders considered arousal to be apparent when the children's gaze shift was relatively quick and spontaneous. Children were explicitly told within the task instructions that they should look straight into the camera and that the video would be shown to other children who are the same age as them. Although very few children held a steady gaze with the camera, all of them attempted to do so. The gaze aversions observed from the camera were extremely similar (and arguably indistinguishable) from the gaze aversions from the experimenter, suggesting that gaze toward the camera was just as socially salient as gaze toward a person who is physically present.

Attention shifting was not considered a gaze aversion within the present coding scheme and was therefore not coded. Attention shifting was evident when the child shifted their gaze in response to a sound, as a result of engaging in descriptive body language, or if they shifted gaze to something they had already been fidgeting with (i.e., hands, MindWare wire). Instances of children closing their eyes or blinking was not coded as a gaze aversion.

2.6.1.3. Positive expressions of shyness. Frequencies of positive expressions of shyness were exported by selecting each time a gaze aversion moved to "elsewhere" during a positive facial expression. The duration of positive shy expressions was exported by selecting the entire time that the child was looking at a non-social stimulus (i.e., elsewhere) while engaging in a positive facial expression. Since frequencies and durations were highly correlated, $r = 0.73$, $p < .010$, a composite score was created by summing z-scored frequency and duration codes.

2.6.1.4. Non-positive expressions of shyness. Although negative expressions of state shyness are commonly investigated within the literature, a non-positive variable (which combines both negative and neutral expressions of state shyness) was created to provide a measure with more variability, since negative expressions of shyness alone are characteristically rare. In the current sample, only 15

Table 1
Correlations and descriptive statistics for all study variables.

	1	2	3	4	5	6	7	8	9	10	11	12	Mean (SD)	Range
1. ToM	–	.10	.35**	-.23	.33**	-.33**	.36**	-.28*	.16	.29*	.21	.00	3.1(1.6)	0–7
2. Resting Baseline RSA		–	-.14	-.03	-.20	-.06	-.18	-.05	-.23	.17	.21	-.02	6.5(1.1)	4.2–8.9
3. Positive Shyness Frequency			–	-.52**	.73**	-.57**	.93**	-.56**	.14	.03	.03	-.03	4.9(4.2)	0–15
4. Non-Positive Shyness Frequency				–	-.55**	.82**	-.57**	.95**	-.27*	.07	.13	-.02	5.0(3.8)	0–14
5. Positive Shyness Duration					–	-.51**	.93**	-.56**	.12	.05	-.03	-.09	7.9(10.0)	0–42
6. Non-Positive Shyness Duration						–	-.59**	.95**	-.16	.06	.13	-.06	11.3(10.0)	0–37
7. Overall Positive Shyness							–	-.61**	.11	.05	-.02	-.06	-0.2(1.8)	-2–4
8. Overall Non-Positive Shyness								–	-.20	.06	.15	-.04	0.1(1.9)	-2–5
9. PVT Scores									–	-.12	-.29**	-.07	109(12)	84–139
10. Age (Months)										–	.14	-.02	55(2.8)	46–60
11. Family Income											–	.13	6.0(1.4)	1–7
12. Maternal Report Trait Shyness												–	11.3(4.4)	5–22

Note. ToM: Theory of Mind; PVT: Picture Vocabulary Test; RSA: respiratory sinus arrhythmia *$p < .05$; **$p < .01$.

children (19%) exhibited *negative* expressions of shyness, and thus we used a measure of *non-positive* shyness which included both negative and neutral facial expressions, which occurred in 91% children ($M_{\text{freq}} = 5.2$, $SD = 3.8$). Characteristic infrequency of negative expressions of shyness are consistent with previous work in this age group (Colonnesi et al., 2017; Nikolic et al., 2016). Although negative expressions of shyness were not correlated with neutral expressions of shyness, we again, attribute this to the infrequency of negative facial expressions that took place in this sample.

Frequencies of non-positive expressions of shyness were exported by selecting each time a gaze aversion moved to "elsewhere" during a neutral or negative facial expression. The duration of non-positive shy expressions was exported by selecting the entire time that the child spent looking at a non-social stimulus (i.e., elsewhere) while engaging in a neutral or negative facial expression. Since frequencies and durations were highly correlated, $r = 0.82$, $p < .010$, a composite score for non-positive shy expressions was created by summing z-scored frequency and duration codes.

2.6.1.5. Additional coded events. Social gaze during positive and non-positive affect were also coded to serve as covariates. Social gaze during positive affect was defined as gaze toward the experimenter or camera with a positive facial expression. Social gaze during non-positive affect was defined as gaze toward the experimenter or camera with a neutral or negative facial expression.

2.7. Maternal report of trait shyness

Mothers reported on their child's trait shyness using the Shyness subscale of the Colorado Childhood Temperament Inventory (CCTI; Buss & Plomin, 1984; Rowe & Plomin, 1977). They reported the degree to which they agreed or disagreed on 5 items set to a scale from 1 to 5 (1 = strongly disagree; 5 = strongly agree). Such statements included "Child tends to be shy" and "Child takes a long time to warm up to strangers". The internal consistency for this scale in the present study was $\alpha = 0.85$.

2.8. Statistical analyses

All analyses were performed in SPSS Version 22 with significance levels set at $\alpha = 0.050$. Pearson correlations were used to assess relations among observed expressions of shyness, resting baseline RSA, and ToM. We then used partial correlations to control for social gaze in order to ensure that relations could not be better explained by positive and non-positive facial expression in general. We further investigated these findings with point-biserial correlations assessing the relations between state shyness and each of the individual ToM tasks. Finally, separate hierarchical linear regressions were used to assess whether resting RSA interacted with observed expressions of positive and non-positive shyness, respectively, when analyzed with respect to ToM. In each regression, we controlled for age (in months), sex, combined family income, PVT scores, and speech duration. Covariates were entered into the first step of the hierarchical analysis, expressions of shyness (i.e., positive or non-positive) and resting RSA were entered in the second step, and the interaction term was entered in the third step. Expressions of shyness, baseline RSA, and covariates were mean centered before analysis and before the creation of the interaction variables.

2.9. Missing data and data loss

Four children were missing ECG data due to recording issues ($n = 2$) or the child's lack of cooperation in wearing the unit or engaging calmly in the baseline procedure ($n = 2$) and were therefore removed from further analyses. These children did not differ on age ($p = .839$), income ($p = .169$), PES ($p = .276$), NPES ($p = .527$), PVT ($p = .709$), or ToM ($p = .282$). Therefore, of the original 78 children in the sample, 4 children were removed due to missing RSA data, and 10 were removed due to poor performance on the comprehension questions from the ToM batteries, resulting in a final sample of 64 children. These 14 eliminated children ranged from 45.9 to 58.7 months of age.

It is important to note that ECG data were also collected during the Birthday Speech Self-Presentation Task in addition to the baseline video. The speech ECG data, however, were unusable and unreliable given the large amounts of artifacts caused by children's motor movements during their speech.

3. Results

3.1. Descriptive statistics and preliminary analyses

Table 1 displays descriptive statistics and correlations among study measures. Overall PES were negatively related to overall NPES, which is in line with previous research using a similar coding scheme and a different sample of children (Colonnesi et al., 2017). The frequency and duration of PES were also negatively related to the frequency and duration of NPES. Trait shyness was not correlated with PES, NPES, nor any other study measures.

PES and ToM were positively related, while NPES were negatively related with ToM, replicating Colonnesi et al. (2017). We performed additional partial correlations to examine the relation among these constructs while controlling for positive and non-positive social gaze (i.e., gaze toward the experimenter or camera). Importantly, PES were still associated with ToM while controlling for positive social gaze and duration of the speech, $r(60) = .30$, $p = .019$, while NPES were still associated with ToM while controlling for non-positive social gaze and duration of the speech, $r(60) = -.28$, $p = .030$, suggesting that the relation between expressions of shyness and ToM were not simply due to the presence of positive or non-positive facial expressions. Point-biserial correlations revealed that, overall, these associations can be mostly explained by children's performance on first-order false-belief tasks. In particular, NPES was negatively associated with performance on the Sally Ann task, $r_{pb}(61) = -.25$, $p = .039$, and the first-order false belief portion of the Miller (2013) task, $r_{pb}(61) = -.31$, $p = .011$. In addition, PES was positively associated with performance on the first-order false belief portion of the Miller (2013) task, $r_{pb}(61) = .32$, $p = .007$.

Resting RSA was not correlated with ToM, nor any other study measures.

3.2. Expressions of shyness by baseline RSA interaction

3.2.1. Positive expressions of shyness

In the hierarchical regression model with PES interacting with baseline RSA, the change in the predictive value of the regression equation was statistically significant at step 1 $\Delta F(5, 58) = 3.17$, $p = .013$, $R^2 = .22$, step 2 $\Delta F(2, 56) = 4.03$, $p = .023$, $R^2 = .31$, $\Delta R^2 = .10$, and step 3 $\Delta F(1, 55) = 5.64$, $p = .021$, $R^2 = 0.38$, $\Delta R^2 = 0.06$ (see Table 2). When covariates, both predictors, and interaction term were present, the interaction term was statistically significant, $b = 0.24$, $t = 2.37$, $p = .021$ (see Fig. 1). As well, PES significantly contributed to this overall model, $b = 0.40$, $t = 3.60$, $p = .001$, suggesting that there was a significant relation between PES and ToM at mean levels of RSA. Age also significantly contributed to the model in all steps. The contribution of PVT was trending toward significance in step 3; however, PVT score was not significant in step 1 or step 2.

This interaction was probed by generating two new regressions to assess the relation between predictor and dependent variable at one standard deviation above and below the mean of resting RSA (Schubert & Jacoby, 2012). The unstandardized simple slope for children with RSA 1 *SD* above the mean was .65 ($p = .001$), while the slope for children with RSA 1 *SD* below the mean was .15 ($p = .209$). As predicted, relatively high PES combined with relatively high baseline RSA was associated with higher levels of ToM when compared to the other PES x RSA combinations, which each yielded moderate ToM (see Fig. 1). When resting RSA was low, children exhibited similar ToM across different levels of PES.

Post hoc statistical power analysis revealed that our sample of 64 with the 8 predictors used in this multiple regression would yield a power of 0.51 for moderate effect sizes ($f \approx 0.39$) and 0.91 for large effect sizes ($f \geq 0.59$). Given that Step 3 of our model resulted in an R^2 of 0.38, which yields a high effect size of $f = 0.78$, we were confident that our sample was large enough for this analysis.

Table 2
Regression analysis assessing the interaction between resting RSA and positive expressions of shyness when analyzed with respect to theory of mind scores in 4-year-old children.

Positive shyness by RSA interaction	*b*	*SE*	*T*	*P*	95% CI	
					Lower bound	Upper bound
Step 1, $R^2 = 0.22$ (Constant)	5.00	0.68	7.31	< 0.001**	3.63	6.36
Age	2.18	0.81	2.71	.009**	0.57	3.80
Sex	0.26	0.19	1.37	.177	-0.12	0.63
Income	0.28	0.21	1.35	.183	-0.13	0.69
PVT	0.41	0.22	1.86	.069	-0.03	0.86
Speech duration	-0.06	0.19	-0.33	.746	-0.44	0.32
Step 2, $R^2 = 0.31$ (Constant)	4.89	0.66	7.46	< 0.001**	3.58	6.20
Age	1.99	0.78	2.56	.013*	0.44	3.55
Sex	0.12	0.19	0.64	.526	-0.25	0.49
Income	0.27	0.20	1.39	.171	-0.12	0.66
PVT	0.38	0.22	1.77	.083	-0.05	0.81
Speech duration	-0.04	0.18	-0.23	.817	-0.41	0.32
Positive shyness	0.30	0.11	2.80	.007**	0.09	0.51
Resting RSA	0.17	0.17	0.97	.337	-0.18	0.51
Step 3, $R^2 = 0.38$ (Constant)	5.33	0.66	8.12	< 0.001**	4.01	6.64
Age	2.40	0.77	3.13	.003**	0.86	3.94
Sex	0.13	0.18	0.75	.460	-0.23	0.49
Income	0.29	0.19	1.53	.132	-0.09	0.67
PVT	0.41	0.21	1.99	.052	-0.01	0.83
Speech duration	-0.12	0.18	-0.68	.501	-0.48	0.24
Positive shyness	0.40	0.11	3.60	.001**	0.18	0.62
Resting RSA	0.25	0.17	1.48	.146	-0.09	0.59
Positive shyness x RSA	0.24	0.10	2.37	.021*	0.04	0.44

*p < .05; **p < .01

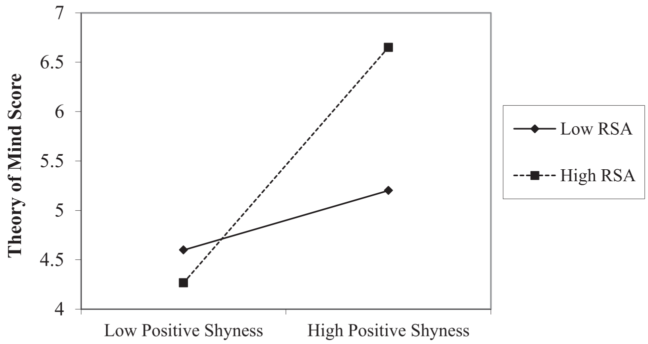

Fig. 1. The interaction between resting respiratory sinus arrhythmia (RSA) and expressions of positive shyness when analyzed with respect to ToM in 4-year-old children.

3.2.2. Non-positive expressions of shyness

Baseline RSA did not interact with NPES when analyzed with respect to ToM,[2] $b = -0.05$, $t = -0.61$, $p = .543$ (see Table 3). However, NPES contributed significantly to the overall model where higher levels of NPES resulted in lower levels of ToM at mean levels of RSA, $b = -0.24$, $t = -2.42$, $p = .019$, replicating prior work. Resting RSA did not contribute significantly to the model, $b = 0.06$, $t = 0.32$, $p = .750$.

4. Discussion

The present study revealed that PES were associated with higher ToM, while NPES were related to lower ToM. We also found that resting RSA, a measure of parasympathetic control and proxy for physiological self-regulation, interacted with PES when analyzed with respect to ToM. As predicted, children with higher baseline RSA and higher PES displayed the highest ToM. We discuss and interpret each of these findings below in turn.

4.1. Relations between expressions of shyness and ToM

The opposing relations of PES and NPES with ToM are consistent with recent findings by Colonnesi et al. (2017). Importantly, however, Colonnesi and colleagues reported that each expression of shyness was related to different ToM task batteries. Specifically, PES were positively associated with more sophisticated ToM, and negative expressions of shyness were inversely related with a more basic battery of ToM tasks. Our study is the first to report these opposing relations in the same battery of ToM tasks, suggesting that PES and NPES may both affect the acquisition of false belief understanding within the same developmental period. Based on our findings, both expressions of shyness appear to most directly affect the attainment of first-order false belief tasks, although more work should be done to further investigate their relations with the developmental sequence of ToM development.

Our findings are also consistent with and extend previous work by Lane et al. (2013), who found that, in preschoolers who experienced high physiological reactivity (i.e., proxy for low physiological control), social withdrawal was negatively associated with ToM. These children were assumed to be socially avoidant and can be compared to children who exhibit high levels of NPES since they had less behaviorally and physiologically adaptive strategies in the context of social cognitive development. Lane and colleagues also found that children who were relatively low in physiological reactivity (i.e., proxy for high physiological control) exhibited a positive relation between social withdrawal and ToM. Similarly, these children can be compared to the participants in our study who displayed relatively high levels of PES since their physiological and behavioral reactions to social stimuli are presumed to reflect a similar approach-avoidance ambivalence.

Most of the existing literature examining shyness and ToM has investigated temperaments rather than state reactions to social evaluation. However, given that these studies report discordant findings regarding the role of trait shyness in ToM development (Kokkinos et al., 2016; LaBounty et al., 2017; Lane et al., 2013; De Rosnay et al., 2014; Wellman et al., 2011), we propose that perhaps the true association exists within heterogeneity of expressions of state shyness and ToM. Of the existing works linking trait shyness and ToM, interpretations seem contingent on the relatively high level of social attentiveness that shy children appear to possess, and perhaps to some extent, on shy children's tendency to observe others rather than participating directly in social interaction (LaBounty et al., 2017; Lane et al., 2013; Wellman et al., 2011). Indeed, shy children are known to possess unique social cognitive strengths, which perhaps evolved as an adaptive mechanism for detecting social threat from unfamiliar conspecifics (Brunet et al., 2009; Hassan et al., 2021; LoBue & Perez-Edgar, 2014; MacGowan et al., 2021; Matsuda et al., 2013). However, theory surrounding the link between trait shyness and ToM may be extended to consider affect-specific heterogeneity in shyness given our present findings.

[2] There was also no interaction between resting RSA and trait shyness when analyzed with respect to ToM, $b = -0.05$, $t = -1.06$, $p = .291$, with shyness not contributing significantly to the model at Step 2, $b = -0.16$, $t = -0.38$, $p = .713$, or Step 3, $b = -0.02$, $t = -0.35$, $p = .732$.

Table 3
Regression analysis assessing the interaction between resting RSA and non-positive expressions of shyness when analyzed with respect to theory of mind scores in 4-year-old children.

Non-positive shyness by RSA interaction						
	b	*SE*	*t*	*p*	95% CI	
					Lower bound	Upper bound
Step 1, R^2 = 0.22 (Constant)	5.00	0.68	7.31	< 0.001**	3.63	6.36
Age	2.18	0.81	2.71	0.009**	0.57	3.80
Sex	0.26	0.19	1.37	0.177	-0.12	0.63
Income	0.28	0.21	1.35	0.183	-0.13	0.69
PVT	0.41	0.22	1.86	0.069	-0.03	0.86
Speech duration	-0.06	0.19	-0.33	0.746	-0.44	0.32
Step 2, R^2 = 0.29 (Constant)	4.99	0.67	7.49	< 0.001**	3.65	6.32
Age	2.16	0.79	2.73	0.008**	0.58	3.74
Sex	0.22	0.18	1.22	0.227	-0.14	0.59
Income	0.33	0.20	1.62	0.111	-0.08	0.73
PVT	0.35	0.22	1.57	0.123	-0.10	0.79
Speech duration	0.01	0.19	0.06	0.956	-0.36	0.39
Non-positive shyness	-0.24	0.10	-2.41	0.019*	-0.44	-0.04
Resting RSA	0.04	0.17	0.23	0.822	-0.31	0.39
Step 3, R^2 = 0.30 (Constant)	5.03	0.67	7.47	< 0.001**	3.70	6.38
Age	2.2.1	0.80	2.77	0.008**	0.61	3.81
Sex	0.25	0.19	1.33	0.188	-0.13	0.64
Income	0.32	0.20	1.60	0.115	-0.08	0.73
PVT	0.36	0.22	1.59	0.118	-0.09	0.80
Speech duration	0.00	0.19	0.00	0.999	-0.38	0.38
Non-positive shyness	-0.24	0.10	-2.42	0.019*	-0.44	-0.04
Resting RSA	0.06	0.18	0.32	0.750	-0.30	0.41
Non-positive shyness x RSA	-0.05	0.09	-0.61	0.543	-0.23	0.12

*p < .05; **p < .01

Children with higher PES, who are more motivated to approach others, may experience higher quality interactions due to their positive affect, which would presumably allow for the interaction to be more enjoyable for themselves and those around them. Therefore, these children may be more inclined to seek out social opportunities, engage with others more often, and may use these occasions to signal affiliation while maintaining enough time and space to gather relevant information regarding possible social threat. The positive nature of these children's social experiences may also cause them to be more motivated to understand the thoughts and intentions of others. Based on these assumptions, the direct relation between PES and ToM abilities observed in the present study is in line with the notion that children who are exposed to social learning opportunities more often may develop ToM at a faster rate or establish expanded social cognitive strengths.

In contrast, children who display high NPES are more motivated to avoid others, presumably discouraging peers from approaching and preventing seamless interaction with new people. Poole and Schmidt (2019) have proposed that negative expressions of shyness may reflect what Buss (1986a, 1986b) describes as a fearful subtype of shyness, and what Kagan and colleagues (1988) characterize as behavioral inhibition, which involves heightened sensitivity to fear and low levels of sociability. Children who express more negative expressions of shyness have been found to experience more social fear (Colonnesi et al., 2014; Poole & Schmidt, 2019), suggesting that this phenotype aligns well with the Emotional Reactivity Hypothesis (ERH; Hare & Tomasello, 2005). The ERH states that individuals who display less fear and aggression tend to develop more sophisticated social cognitive abilities. This theory, which is often considered in non-human animal behavior, can be extended to the ontogenetic development of children: as aggression and fear increase, capacity for social cognitive ability decreases (LaBounty et al., 2017; Lane et al., 2013; Wellman et al., 2011).

In the present study, trait shyness and ToM were not statistically related to one another, suggesting that expressions of state, rather than trait, shyness serve as sensitive and valuable measures that may contribute to the development of ToM. Parent-reported trait shyness provides a more general and undifferentiated measure of anxious self-preoccupation, which appears not to capture the heterogeneity necessary to fully explain this relation. These findings are important in the context of the historically discordant results regarding the relation between shyness and ToM and call for future assessments of heterogeneity within state shyness when examining other relevant child outcomes.

Alongside these arguments, we would like to acknowledge that the relation between shyness and ToM is undoubtedly complex, and causation is difficult to establish. Based on existing interpretations, most have assumed that shyness precedes and therefore predicts the development of social cognitive abilities (LaBounty et al., 2017; Lane et al., 2013; Longobardi et al., 2017; Mink et al., 2014; Wellman et al., 2011). To our knowledge, only a few studies have investigated ToM and other social cognitive abilities as predictors for later temperament outcomes (e.g., Song et al., 2016). However, the degree to which temperament and social cognition have transactional affects on one another throughout development remains an empirical question and is an important area for future research.

4.2. Influence of RSA on relations between expressions of shyness and ToM

This study extended previous work on state shyness and ToM by reporting an interaction between resting RSA, a measure of parasympathetic control and proxy for physiological self-regulation, and PES when analyzed with respect to ToM. As predicted, children who experienced high baseline RSA combined with high PES displayed the most sophisticated ToM when compared to children with other RSA by PES combinations.

These results extend and further contextualize our correlational findings by highlighting that PES was related to higher ToM, but only in the presence of more adaptable parasympathetic control (i.e., relatively high RSA). Children who express adaptive behavioral and affective signals combined with advantageous physiological capacities are likely capable of concurrently adjusting to changes in the environment (i.e., parasympathetic control) while using positive facial expression to signal appeasement to strangers. This phenotype is presumably optimal for smooth social interactions as well as social processing and observation of others. This combination not only allows for more frequent social learning opportunities with novel peers and adults, but also for the physiological reduction of arousal elicited by social situations that may be stressful and overwhelming for some children.

Children with lower RSA had similar ToM across different levels of PES. It is possible that individuals with low resting RSA may not reap the same regulatory benefits of high PES when compared to children with high RSA, since they are less capable of effectively and flexibly adapting to the changing demands of the social environment. These findings strengthen the notion that biological predispositions are important to consider when analyzing individual differences in trait and state shyness as well as the development of social-cognitive processes.

This interaction was detected during an age at which children are being exposed to more social situations with new peers (i.e., preschool, daycare, kindergarten), and are beginning to understand the intentions, beliefs, and feelings of others. It is expected that encountering novel individuals and being responsible for one’s own communication, for perhaps the first time, can be overwhelming. Heightened arousal in such situations can presumably impede both the observation of others and the likelihood to interact with peers. It appears that children who possess both a behavioral strategy and physiological capacity to regulate this arousal may develop ToM (mostly notably first-order false belief) at a somewhat faster rate than children who possess only one or neither of these abilities. Further work should establish the causality of these relations as well as the degree to which this interaction of variables can have longitudinal effects on children’s socio-cognitive development.

The interaction between RSA and NPES was not significant when analyzed with respect to ToM. Children exhibited lower levels of ToM as NPES increased, regardless of resting RSA. These findings suggest that ’favorable’ resting RSA may not be sufficient in acting as a protective factor against high levels of NPES. However, children who displayed high NPES and low resting RSA did not perform worse on the ToM tasks when compared to children with relatively high NPES and higher resting RSA. This suggests that resting RSA may only reinforce social inference when children possess relatively high PES.

It is important to note that we may have detected an interaction between RSA and *negative* expressions of shyness (NES) if more children in our sample had engaged in these behaviors. We suspect that NES may serve as a more emotionally salient negative reaction to social exposure when compared to NPES. However, most studies assessing state shyness within this age group detect low occurrences of NES, with many children not engaging in this expression at all (e.g., Colonnesi et al., 2014, 2017).

4.3. Strengths and limitations

There were several strengths to our study, including children’s expressions of shyness coded from direct observation, a biological measure of parasympathetic control, multiple tasks to derive a measure of ToM, and the consideration of a developmental period which coincides with the emergence of false belief understanding. Our study also assessed both frequency and duration of PES and NPES, providing information on number of gaze aversions as well as the length of time that the child looked away from social stimuli.

This study also has some limitations that are important to consider. First, since the current sample was primarily White, with a high average family income, the extent to which are findings would generalize to more ethnically and economically diverse groups is unknown. Second, the findings of the present study were based on concurrent correlations and a cross-sectional design, limiting causal inferences.

Future work should examine expressions of shyness and ToM longitudinally to explore possible age-related and developmental differences that may exist within these relations from infancy to adolescence. In particular, cross-lagged designs could further evaluate the direction of these relations (Song et al., 2016; Wellman et al., 2011). It would also be beneficial to determine if expressions of shyness serve as possible mediators between ToM and the development of certain problematic social outcomes such as low social competence and peer rejection. Identifying these mechanisms would allow for possible intervention before such problems arise at or around the time of formal school entry. Future work should also investigate the role of early parasympathetic control and physiological self-regulation (i.e., resting RSA and RSA change, respectively) in the longitudinal development of ToM, PES, and other relevant adaptive strategies for social functioning. Finally, it is important to explore these relations in more culturally and ethnically diverse samples to enhance the generalizability of these findings.

5. Conclusion

We have provided evidence that heterogeneity within expressions of state shyness contributes to ToM understanding in 4-year-old children; PES appear to reinforce ToM in the context of high parasympathetic control while NPES may hinder false belief understanding regardless of physiological self-regulatory capacity. Our findings suggest that children with relatively high resting RSA and high PES experience adaptive appeasement and regulatory functions during social interactions, conferring the highest levels of ToM compared to other RSA by shyness combinations. Our work extends prior findings and strengthens the importance of considering heterogeneity in shyness and parasympathetic control when considering the development of social-cognitive processes in early childhood.

Data availability

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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Conflict of Interest

The authors have no conflicts of interest to declare.

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