Children's Autonomic Nervous System Activity While Transgressing: Relations to Guilt Feelings and Aggression

Tyler Colasante, Antonio Zuffianò, David W. Haley, and Tina Malti

Author Note

Tyler Colasante, Department of Psychology, University of Toronto; Antonio Zuffianò, Department of Psychology, Liverpool Hope University; David W. Haley, Department of Psychology, University of Toronto; Tina Malti, Department of Psychology and Department of Psychiatry, University of Toronto.

This research was supported by a Canadian Institutes of Health Research Foundation Scheme grant (FDN-148389) awarded to Tina Malti. The authors thank the children and caregivers who participated, and the members of the Laboratory for Social-Emotional Development and Intervention who helped with data collection, entry, and coding.

Correspondence concerning this article should be addressed to Tyler Colasante, Department of Psychology, University of Toronto, 3359 Mississauga Rd, Mississauga, ON L5L 1C6, Canada. E-mail: tyler.colasante@mail.utoronto.ca.

Abstract

Despite the well-established protective functions of guilt across childhood, its underlying physiological mechanisms have received little attention. We used latent difference scores to model changes in children's (*N* = 267 4- and 8-year-olds, 51% girls) skin conductance and respiratory sinus arrhythmia while they imagined themselves committing antisocial acts. We then tested if their later reports of guilt, caregiver-reported aggressive behavior, and age were associated with these physiological changes. For 8-year-olds, changes in respiratory sinus arrhythmia leading up to and during transgressions were uniquely associated with the intensity of guilt feelings after transgressions. Eight-year-olds with higher guilt were rated lower in aggression, although children's physiology and aggression were not directly related. We discuss how fluctuations in physiology while transgressing may prepare children to mount adaptive guilt responses afterward and—more broadly—implications for understanding the mechanisms behind guilt and related behavior in early and middle childhood.

Keywords: skin conductance, respiratory sinus arrhythmia, guilt, aggression, childhood, latent difference score modeling

Children's Autonomic Nervous System Activity While Transgressing: Relations to Guilt Feelings and Aggression

Feeling guilt after transgressing against others dissuades children from aggressive behavior as they develop (Malti & Krettenauer, 2013) and has long been regarded as a cornerstone of the human conscience (Freud, 1930/1994). The experience of guilt can be broken down into components (e.g., an eliciting event, a cognitive appraisal of the event, a physiological change, a bodily expression, and an action tendency; Scherer, 2009). Developmental research has primarily focused on its eliciting events (e.g., how different social contexts elicit different intensities of guilt; Malti & Ongley, 2014) and corresponding action tendencies (e.g., links between guilt and antisocial behaviors, such as aggression and delinquency; Malti & Krettenauer, 2013). Relatively little emphasis has been placed on mechanistic processes, such as physiology, that occur between these respective start and end points. Children vary considerably in their capacity to regulate physiological arousal (Alkon et al., 2003) and this capacity likely plays an important role in shaping the affective and behavioral responses that manifest to us as researchers. Whether or not children arrive at guilt and avoid aggressive outcomes, then, likely depends on their physiological capacities to regulate and respond to the nuances of social conflicts.

The scant research on children's physiology and social emotions has often relied on single autonomic nervous system (ANS) measures and analytic approaches that fail to capture children's social-emotional experiences as they unfold in real time (Kahle & Hastings, 2015). In the current study, we used a latent statistical approach to model children's dynamic ANS responses while they hypothetically transgressed. We then tested the extent to which differences in later guilt feelings and caregiver-reported aggressive behavior were associated with differences in these physiological responses.

Although we know that verbal expressions of guilt become more frequent, sophisticated, and likely internalized from early to middle childhood (Hoffman, 2000; Malti, 2016; Nunner-Winkler & Sodian, 1988), we know much less about how underlying components of guilt factor into these changes. By investigating the physiological component of guilt in 4- versus 8-year-olds, we aimed to gain a more nuanced understanding of how guilt develops across this critical juncture of childhood.

The Importance of Guilt for Children's Healthy Development

Guilt—commonly referred to as a feeling of regret over wrongdoing—involves accepting responsibility for causing or associating oneself with a past or potential transgression (Kochanska, Gross, Lin, & Nichols, 2002; Malti, Gummerum, Keller, & Buchmann, 2009). Feeling guilt is an inherently social experience because it often requires children to balance their own and others' perspectives (e.g., by recognizing that their happiness after stealing a desired object comes at the expense of negative emotions and consequences for the original owner; Malti, Dys, Colasante, & Peplak, 2017). In addition to being a social emotion, guilt can be further classified as moral versus nonmoral (Malti, 2016). Moral guilt stems from a violation of an internalized moral principle (e.g., fairness, justice, or abstaining from harm) and/or concern for the welfare of others (Hoffman, 2000). Nonmoral guilt, on the other hand, occurs after violating a social-conventional principle (e.g., a classroom rule) and/or revolves around the sanctions associated with an undesirable action (e.g., punishment from a parent; Malti et al., 2017). From a theoretical perspective, moral—relative to nonmoral—guilt is more likely to be intrinsically motivated, stable, and linked to dispositional aggressive behaviors (Colasante, Zuffianò, & Malti, 2016; Malti, 2016). We therefore focused on disentangling children's moral guilt responses in the present study.

To assess guilt feelings in an experimental setting, developmental psychologists typically—with the help of stories—ask children to attribute emotions and justifications to themselves as hypothetical victimizers. These responses are then coded for the presence of guilt (Arsenio, 2014; Malti & Ongley, 2014). The role of guilt in protecting against children's maladaptive aggressive outcomes has received considerable empirical support. A meta-analytic review of 42 studies, for instance, found a significant negative association between children's and adolescents' attributions of guilt feelings and aggressive behavior (majority ages 7–10; d = .39; Malti & Krettenauer, 2013). Guilt and related emotions (e.g., empathy) are often conceptualized as consequential, occurring in response to a moral transgression or another's suffering that already happened and thereby motivating reparative actions (Malti et al., 2017). However, consequential guilt is unique because it may also spur future instances of anticipatory guilt over similar transgressions before they occur (Tangney, Stuewig, & Mashek, 2007). Thus, guilt can serve as an emotional barometer that helps children determine the extent to which a past or prospective aggressive act misaligns with their internalized moral principles and/or distresses others.

From a developmental perspective, children's tendency for guilt is relatively well established by middle childhood (Hoffman, 2000; Malti, 2016; Nunner-Winkler & Sodian, 1988) and may be linked to significant long-term behavioral implications. A recent longitudinal study found that guilt proneness in late childhood (ages 10–12) predicted less involvement with the criminal justice system in early adulthood (ages 18–21; Stuewig et al., 2015). This underscores the importance of understanding the emergence of guilt's multifaceted components, such as corresponding physiology, and their early correlates. However, the underlying mechanisms that potentially give rise to children's reports of guilt have received much less empirical attention than the observed components and versatile protective functions of such feelings.

The Physiology of Children's Guilt

Emotions have many components, with each one considered an important ingredient for understanding when and how a given emotion will manifest (Moors, 2009; Scherer, 2009). The physiological component of emotions is commonly measured via ANS activity (Kreibig, 2010). The branches of the ANS—the sympathetic and parasympathetic nervous systems (SNS and PNS, respectively)—selectively and jointly innervate the body's tissues and organs, and rapidly prepare it for challenging emotional situations (Kreibig, 2010). Children's ANS responses while hypothetically transgressing can therefore be assumed to play a meaningful role in their expressions of guilt (or lack thereof) following such transgressions.

Much of the developmental literature linking ANS activity to emotions has focused on basic emotions, with earlier work centered on heart rate (HR) acceleration and deceleration as global ANS indicators of arousal- and attention-related emotional processes, respectively (Bradley & Lang, 2007; Cacioppo & Sandman, 1978; Lansink & Richards, 1997; Richards & Cronise, 2000). In terms of specific emotions, anger and fear induction have been reliably associated with HR acceleration in early and middle childhood (e.g., Field & Schorah, 2007; Lewis, Ramsay, & Sullivan, 2006; Weems, Zakem, Costa, Cannon, & Watts, 2005). Although investigations of children's HR and sadness are less common, an interesting study by Miller and Wood (1997) found that a sad versus neutral film clip (i.e., the death scene versus opening credits of the movie *E.T., The Extra-Terrestrial*) was linked to greater HR deceleration in 8- to 17-year-olds. To some extent, these findings have been extended to the moral realm. For example, children who showed greater HR acceleration in response to videos depicting bullying reported more intense anger after each video and were rated by peers as more likely to stop a bully in their day-to-day lives (Barhight, Hubbard, & Hyde, 2013). A number of earlier studies found that children with higher empathy—who also tend to experience more guilt after transgressing against others—showed greater HR deceleration in response to videos depicting individuals in distress (e.g., Eisenberg et al., 1989; Eisenberg et al., 1990; Eisenberg, Fabes, Schaller, Carlo, & Miller, 1991). However, the empathy–physiology literature has been plagued by inconsistencies (e.g., Anastassiou-Hadjicharalambous & Warden, 2007; Eisenberg et al., 1992; Zahn-Waxler, Cole, Welsh, & Fox, 1995), which, among other factors, may stem from HR reactivity being dually innervated by the SNS and PNS (Hastings, Miller, Kahle, & Zahn-Waxler, 2014; Kreibig, 2010). Different measurements of empathy across studies may have resulted in differential SNS and PNS influences on the directionality of HR reactivity. Given that guilt is a similar social-emotional response, accounting for its complexity likely requires the consideration and interpretational value of multiple ANS markers, including SNS- and PNS-specific correlates.

In general, the sympathetic "fight or flight" branch of the ANS prepares the body for activity, whereas the parasympathetic "rest and digest" branch is linked to restorative actions, such as attentional and emotional control. Under SNS influence, postganglionic neurons release acetylcholine, which stimulates the eccrine or sweat glands of the skin. The electrical conductivity of resulting skin moisture (i.e., skin conductance [SC] level) can therefore serve as a reliable indicator of SNS activity (Dawson, Schell, & Filion, 2007). Lower levels of SC during lab-based stressor tasks, indicative of affective underarousal, have been associated with a higher incidence of externalizing behavior problems (Lorber, 2004), suggesting that such children lack the physiological responsiveness to deter them from harmful acts. Moreover, Baker, Baibazarova, Ktistaki, Shelton, and van Goozen (2012) found that observed fearlessness in infancy predicted lower SC and lower observed guilt in response to a guilt induction paradigm at age 3. Thus, children in the present study with higher guilt and lower aggression may be expected to exhibit higher levels of SC while hypothetically transgressing (to the extent they find antisocial acts disruptive and affectively arousing).

Respiratory sinus arrhythmia (RSA) is a common measure of PNS activity. Specifically, RSA is a calculation that represents the influence of one's vagus nerve on the coupling of their respiratory cycle and HR. Typically, the vagus nerve serves as a "brake" that maintains or slows HR. In challenging situations, however, the vagal brake is withdrawn (represented by RSA decreases), resulting in HR increases that are thought to facilitate an emotional and/or behavioral response to environmental demands (see polyvagal theory; Porges, 2011). Indeed, emotion inductions and social, cognitive, and emotional challenges (e.g., executive functioning and stressor tasks) have been shown to elicit RSA decreases in children (Beauchaine, 2001; Graziano & Derefinko, 2013). RSA decreases while hypothetically transgressing, then, may be associated with higher guilt afterwards and lower ratings of aggression. Specifically, children's degree of RSA withdrawal may reflect their engagement with the mental exercise as a social challenge and/or their orienting to morally salient emotional stimuli, such as the victim.

Developmental Differences in the Physiology of Children's Guilt

Although children as young as 3 years appear to grasp the concepts of right and wrong (Turiel, 1983), they often report positively valenced emotions in the role of victimizer (e.g., after hypothetically stealing a chocolate bar from another child). Researchers have dubbed this the ‘‘happy victimizer phenomenon" (Arsenio, 2014; Malti & Ongley, 2014). By 7 or 8 years of age, children report less happiness and more guilt over wrongdoing. This shift towards acknowledging the negative consequences that transgressions have on others is likely due, in part, to codeveloping facets of self-regulation and perspective-taking (Eisenberg, Spinrad, & Eggum, 2010; Malti & Ongley, 2014). Even if children reliably express guilt in early childhood, they are thought to experience a gradual internalization of guilt feelings across childhood (i.e., shifting from strict compliance with parental standards to adopting moral principles as one's own; Hoffman, 2000).

The extent to which developmental increases in expressed guilt are reflected in its underlying components remains unclear. As the frequency, complexity, and self-relevance of guilt increase from early to middle childhood, we may expect changes in its underlying ANS correlates. Alternatively, general maturational changes in the ANS may prompt differential associations between ANS activity and guilt across childhood. Children's resting RSA has been shown to increase from infancy to approximately 5 years of age (Alkon, Boyce, Davis, & Eskenazi, 2011) and from 8 to 10 years of age (Hinnant, Elmore-Staton, & El-Sheikh, 2011), with decreases and stability in resting SNS, respectively. Limited evidence also indicates more RSA-dominant ANS reactivity in older versus younger children (among 3- to 8-year-olds; Alkon et al., 2003). Collectively, these studies suggest that ANS activity—and its potential links with guilt—may fall under increasing PNS influence across childhood.

The Present Study

We used latent statistical analyses to model 4- and 8-year-olds' ANS (i.e., SC and RSA) responses across three intervals (i.e., at baseline, leading up to hypothetical transgressions, and during such transgressions). We then assessed these physiological responses in relation to children's reports of guilt feelings after transgressing and their caregiver-reported aggressive behavior. This comprehensive approach was in response to the current state of developmental literature on physiology and emotions, for which we identified four significant gaps. First, there is a marked lack of developmental research on the ANS correlates of guilt, which may shed considerable light on the underlying regulatory processes of such feelings. Second, the few studies on children's ANS and other social emotions—namely empathy—rarely considered a) more than one ANS measure and b) if such measures extended to account for social behavior. Third, these studies tended to rely on relatively simple statistical and methodological approaches (e.g., difference scores that averaged ANS responses at baseline and across entire emotion-based tasks). Such approaches may dilute important fluctuations between the distinct stages of emotional events (Hastings et al., 2014; for recent exceptions, see Cui et al., 2015; Miller, Kahle, & Hastings, 2015; Miller, Nuselovici, & Hastings, 2016). Children's guilt, in particular, is a dynamic emotional process that encompasses their responses to multifaceted social conflicts as they unfold (Malti, 2016; Malti et al., 2017). Fourth, developmental differences in the ANS correlates of guilt have yet to be investigated.

Overall, we hypothesized that children who showed greater SC increases and RSA decreases while they imagined transgressing (reflecting more arousal over transgressing and more engagement with/orienting to morally salient emotional stimuli [for a similar interpretation, see Baker et al., 2012]) would express higher levels of guilt afterward and receive lower ratings of aggressive behavior. Given the well-documented age-graded progression of guilt expressions from early to middle childhood (Malti & Ongley, 2014), we expected 8-year-olds to report more guilt. In line with maturational increases in task-related PNS activity (relative to SNS activity; Alkon et al., 2003), we also remained open to the possibility that older children's reports of guilt would be more strongly associated with dynamic RSA than dynamic SC (and vice versa for younger children). Finally, we controlled for gender and socioeconomic status (SES) in light of previous studies linking gender to ANS activity (e.g., Eisenberg et al., 1991), guilt (Malti & Ongley, 2014), and aggression (e.g., Nivette, Eisner, Malti, & Ribeaud, 2014), and SES to ANS activity (e.g., Obradović, Bush, Stamperdahl, Adler, & Boyce, 2010), guilt (e.g., Frick, Kimonis, Dandreaux, & Farell, 2003), and aggression (e.g., Ludwig, Duncan, & Hirschfield, 2001).

Method

Participants

An ethnically diverse community sample of 134 4-year-olds (M_{age} = 4.53, *SD* = 0.31, 68 girls [51%]) and 133 8-year-olds (M_{age} = 8.54, *SD* = 0.32, 68 girls [51%]) participated alongside their primary caregivers (*N* = 267, 136 girls [51%]). They resided in a major Canadian city and were recruited from local community centers, events, and summer camps. The sole exclusion criterion was the presence of an autism spectrum disorder. All children were fluent in English (speaking and comprehension), as were their caregivers (speaking, comprehension, and writing). Caregivers reported their highest level of education—as a proxy of SES—with the following breakdown: 46% bachelor's, 20% master's, 17% college, 4% doctoral, 3% high school, and 2% apprenticeship/trade level (8% missing/chose not to report). The sample included 26% multiple/other, 22% Middle Eastern, 12% South or Southeast Asian, 9% American, 7% East Asian, 5% Western European, 5% Central or South American, 4% Eastern European, and 1% African origins (9% missing/chose not to report). Overall, these distributions were representative of the suburban region from which the sample was drawn (Statistics Canada, 2013).

Procedure

The researchers' institution granted ethical approval. Children and caregivers attended the laboratory for a single 60- to 90-minute session. Oral assent was obtained from children and written informed consent was obtained from caregivers. Children were outfitted with physiological equipment. Child assessments were then conducted in a designated room while caregivers remained in a waiting area and completed a questionnaire. At study end, caregivers were debriefed while children were awarded an age-appropriate book.

Measures

Guilt. Children were presented two stories depicting intentional antisocial acts (i.e., stealing a chocolate bar from another child and pushing another child out of line to get the only remaining lollipop) from the Social-Emotional Responding Task (SERT), which has been widely used and validated across different ages, samples, and countries (Malti et al., 2009; Malti & Ongley, 2014). Each story was presented on a computer with prerecorded audio clips and visuals depicting a) a pretransgression portion in which the desirable object (i.e., chocolate bar or lollipop) was introduced and b) a transgression portion in which the antisocial act (i.e., stealing or pushing) was committed to achieve the desirable object. Because we were interested in children's real-time physiological responding while transgressing, the stories were presented from a first-person perspective. Children were instructed to sit still and face the computer screen while the audio and visuals directed them to imagine themselves engaging with the pretransgression content and committing the transgression (Figure 1). To further immerse children, all audio and visuals were matched to their gender and skin tone (as applicable). In addition, the stories were randomly presented, delivered at a developmentally appropriate pace, and of roughly equal length. Before the stories, children were given a perspective-training task in which the experimenter provided them with a tennis ball and asked them to hold it in front of them with its logo visible and upright. Children were then shown a gender- and skin tone-matched picture on the computer screen replicating their arm and hand holding the ball. Once the child recognized herself or himself as the protagonist in the picture, the experimenter proceeded to the test stories (if children failed at their first attempt, the experimenter re-administered the task until they understood).

Four questions followed each story: question 1 asked, “How would you feel if you did this?” If children said, “I don’t know”, they were asked, “If you had [transgression depicted in story], would you feel good, bad, or good and bad?” Question 2 asked, “Why would you feel [anticipated emotion from question 1]?” Children’s answers to this were recorded verbatim. Question 3 asked, “How strongly would you feel [anticipated emotion from question 1]?” Children answered this by pointing to a 3-point scale depicting squares of increasing size. As a control, question 4 asked, “How much do you like [desirable object from story]?” Children responded with the same 3-point scale. Prior to this, 4-year-olds were calibrated with a similar scale depicting animals of increasing size (i.e., a mouse, a horse, and an elephant corresponding to *low*, *medium*, and *high* intensity emotions/preferences, respectively) to ensure they understood the scale format (Ongley & Malti, 2014). Preference scores (i.e., responses to question 4) were aggregated across stories for use in further analyses (r = .32, p = .002 and r = .31, p = .001 for 4- and 8-year-olds, respectively).

Coding. Children’s responses to the SERT were coded for guilt based on a well-validated scheme (Malti et al., 2009; Ongley & Malti, 2014). Reported emotions following question 1 were coded as 1 (*guilt related*) or 0 (*not guilt related*). Specifically, *bad*, *sad*, *guilty*, and other guilt-related negative emotions were coded as 1, whereas *neutral*, *happy*, *proud*, *good*, *fearful*, *anxious*, and other negative emotions that were not guilt related were coded as 0. Including simplified reports of negative feelings, such as bad and sad, allowed us to examine affective precursors of guilt in younger children who may not have been able to verbalize guilt, but were able to name its basic emotional correlates and provide consonant reasoning (Ongley & Malti, 2014; Tracy, Robins, & Lagattuta, 2005). Children's reasoning following question 2 was coded as 1 (*moral*; i.e., references to violating moral principles of fairness, justice, and/or harm, or to the welfare of others; e.g., "It's not fair", "He'll be sad"), 2 (*sanction based*; i.e., references to external sanctions from authority figures or peers; e.g., "I'll get in trouble by the teacher"), 3 (*hedonistic/justifying*; i.e., references to self-centered benefits/excuses for why it was acceptable to transgress; e.g., "I love chocolate"), or 4 (*unelaborated/other*; e.g., "It's bad…I don't know"). Only responses coded as 1 (*guilt related*) for question 1 and 1 (*moral*) for question 2 were deemed indicative of guilt. To add further gradation, we used the corresponding intensity scores of guilt responses (1 = *not strong guilt* to 3 = *very strong guilt*). A score of 0 was retained for responses other than guilt. Resulting continuous scores were aggregated across stories ($r = .56$, $p < .001$ and $r = .45$, $p < .001$ for 4- and 8-year-olds, respectively). Two independent raters coded the anticipated emotions and reasoning from each story. Cohen's κs were .96 and .79, respectively. Disagreements were discussed until a consensus was reached.

Dynamic ANS (SC and RSA) responses. Electrodermal (EDA) and electrocardiogram (ECG) data were recorded from children at a sampling rate of 2 kHz using a Biopac MP150 data acquisition system and BioNomadix modules (Biopac Systems, Goleta, CA, USA). EDA monitoring electrodes were secured to the tips of the index and ring fingers of children's nondominant hands. ECG monitoring electrodes were secured slightly below their right clavicles and below their ribs on both sides. Leads from the electrodes were connected to EDA and ECG modules fastened around their wrists and midsections, respectively, that communicated wirelessly via the MP150 with a computer in an adjacent room running AcqKnowledge 4.2 data acquisition software (Biopac Systems, Goleta, CA, USA).

EDA and ECG data were imported to EDA 3.0.25 and HRV 3.0.25 software (Mindware Technologies, Gahanna, OH, USA) for visual inspection, cleaning, and calculations of SC and RSA. Physiological recordings were synchronized with story presentations using The Observer XT (Noldus Information Technology, Leesburg, VA, USA), which permitted us to extract each child's average SC and RSA values for three standardized intervals: a) a 120-second baseline (i.e., in response to a nondescript video depicting aquatic scenery), b) the pretransgression portion of each story (chocolate bar = 17.02 seconds, lollipop = 11.84 seconds), and c) the transgression portion of each story (chocolate bar = 10.69 seconds, lollipop = 16.66 seconds). If more than 20% of an interval required cleaning, it was excluded from analyses (overall rejection rate = 14.86%).

Aggressive behavior. Caregivers completed eight matched items from the narrow-band Aggressive Behavior syndrome scales of the Child Behavior Checklists for 1.5- to 5- and 6- to 18-year-olds (CBCL/1.5-5 and CBCL/6-18; Achenbach & Rescorla, 2000, 2001; e.g., "physically attacks people", "destroys things belonging to his/her family or others") on a 7-point scale from 0 to 6 (0 = *never*, 3 = *about half the time*, 6 = *always*; α = .78 and .84 for 4- and 8-year-olds, respectively).

Data Reduction

For the purposes of the current study, it was important that spontaneous physiological responding was tested against verbal responses that met our coding criteria for guilt or lack thereof. It was impossible for us to ascertain if children with unelaborated/other responses to the justification question of the SERT (i.e., question 2: "Why would you feel [anticipated emotion from question 1]?") were guilty or not guilty for moral reasons. To control for potential obscuring or confounding influences of such responses on the physiology–guilt link, we excluded children who provided unelaborated/other responses to both stories from our analyses (*n* = 40 4-year-olds and *n* = 12 8-year-olds). We retained those who provided such responses to one of the two stories (*n* = 56 4-year-olds and *n* = 18 8-year-olds), but coded their physiology, guilt, and preference scores for the story with an unelaborated/other response as missing. Consistent with previous studies, unelaborated/other responses were more common in younger children (Malti et al., 2009; Ongley & Malti, 2014). To ensure that excluded 4-year-olds did not significantly differ from included 4-year-olds in other important ways, we ran a series of Bonferroni-corrected *t*-tests comparing their physiology (at baseline, pretransgression, and transgression), aggression ratings, preferences, gender, and SES. None of which reached significance (final sample excluding cases based on missingness across all variables: *N* = 190 [*n* = 80 4-year-olds and *n* = 110 8-year-olds]).

Data Analytic Approach

We used a latent structural equation modeling approach (Kline, 2016) in Mplus 7.4 (Muthén & Muthén, 2012) to analyze children's dynamic SC and RSA across our intervals of interest. First, we created latent variables for SC and RSA at pretransgression and transgression from sets of two tau-equivalent indicators (i.e., the observed SC and RSA scores from the pretransgression and transgression portions of the chocolate bar and lollipop stories, respectively; Figure 2).[1] In other words, we created latent physiological variables for each portion from what was shared between children's physiology for the chocolate bar and lollipop stories. Next, we used latent difference scores (LDS) to model children's mean-level changes in SC and RSA in relation to their guilt, aggressive behavior, and age group. Within the LDS framework, the difference between two latent factors ($f[2]$ - $f[1]$) is modeled by a third latent factor (Δf), which

[1] Given the presence of one indicator for each of baseline SC and baseline RSA, we estimated them as mock latent variables by fixing their residual variances to zero, which allowed for model identification (Figures 2 and 3).

captures the part of $f[2]$ that is unique from $f[1]$. This is reached by fixing the regression coefficient between $f[1]$ and $f[2]$ to 1 and freely estimating the residual component of $f[2]$ (i.e., Δf) so that $f[2]$ can be re-expressed as $f[2] = f[1] + \Delta f$. The latent change factor (i.e., Δf) is characterized by a mean (i.e., the average mean-level increase or decrease between the two points) and a variance (i.e., differences between individuals in this mean-level change). This allows the researcher to a) simultaneously analyze interindividual differences in intraindividual change and b) estimate relations between latent change and initial levels (McArdle, 2009). The LDS framework was particularly appropriate for the current study because it allowed us to account for measurement errors endemic to physiological assessments (Burt & Obradović, 2013) and thereby isolate true physiological change scores between our intervals of interest: a) from baseline to pretransgression (i.e., while children engaged with the desirable objects) and b) from pretransgression to transgression (i.e., while they transgressed to achieve the desirable objects). Since the χ^2 test is sensitive to sample size, we also relied on the following indices as alternative indicators of acceptable fit: a comparative fit index (CFI) and Tucker-Lewis index (TLI) > .90, and a root mean square error of approximation (RMSEA) < .08 with 90% confidence intervals (CI). Finally, we used maximum likelihood with standard errors robust to nonnormality as a method of estimation.

Results

Developmental Differences and Zero-Order Correlations

Table 1 displays the means and standard deviations of study variables by age group. Bonferroni-corrected *t*-tests revealed significant developmental differences. In comparison to 4-year-olds, 8-year-olds reported higher levels of guilt after transgressing, $t(210.10) = -9.05$, $p < 0.001$. For absolute levels of physiology, 8-year-olds had lower SC at baseline, $t(123.76) = 3.88$,

$p < 0.001$, pretransgression, $t(141.20) = 3.69$, $p < 0.001$, and transgression, $t(141.19) = 3.58$, $p < 0.001$, and higher RSA at baseline, $t(186) = -2.97$, $p = .003$. They were also rated as less aggressive by caregivers, $t(209) = 5.32$, $p < 0.001$, and tended to prefer the desirable objects less than 4-year-olds, $t(211.34) = 5.56$, $p < 0.001$. Zero-order correlations by age group are displayed in Table 2. Notably, higher levels of reported guilt were associated with lower ratings of aggressive behavior among 8-year-olds. Both 4- and 8-year-olds' SC and RSA scores showed high rank-order stability.

Dynamic SC and RSA: Relations to Guilt and Aggression, and Developmental Effects

As a preliminary step, we ran separate unconditional univariate LDS models to assess SC and RSA from baseline to pretransgression (i.e., change segment 1; $\Delta f[1]$) and from pretransgression to transgression (i.e., change segment 2; $\Delta f[2]$). The LDS models for SC, $\chi^2(5) = 8.41$, $p = .13$, CFI = 1.00, TLI = .99, RMSEA = .06, 90% CI [.00, .13], and RSA, $\chi^2(7) = 13.24$, $p = .07$, CFI = .98, TLI = .98, RMSEA = .07, 90% CI [.00, .12], had excellent fit. SC and RSA showed opposite mean-level changes across the intervals. Whereas SC was characterized by an increase from baseline to pretransgression ($\Delta SC[1]$) and a decrease from pretransgression to transgression ($\Delta SC[2]$), RSA showed a decrease in $\Delta RSA[1]$ followed by an increase in $\Delta RSA[2]$ (Table 3). In terms of interindividual differences, children varied significantly in their SC and RSA at baseline and across the first change segments.

To assess differences in children's dynamic ANS activity based on their levels of guilt and aggression, we ran a conditional bivariate LDS model simultaneously predicting latent change scores in SC and RSA from guilt, aggression, age group, and the following control variables: preference, gender, and SES. This model fit the data very well, $\chi^2(52) = 67.20$, $p = .08$, CFI = .99, TLI = .99, RMSEA = .04, 90% CI [.00, .06], and explained a small-to-moderate amount of variance in dynamic SC (R^2 = .05 for ΔSC[1] and R^2 = .22 for ΔSC[2]) and dynamic RSA (R^2 = .27 for ΔRSA[1] and R^2 = .19 for ΔRSA[2]). However, none of the predictors were uniquely and significantly related to physiological changes at $p < .05$. Also against our general expectations, latent changes in SC and RSA were not significantly correlated.

Next, we explored developmental differences in the effects of our focal predictors (i.e., guilt and aggression) on dynamic SC and RSA by adding the interactions of Guilt x Age Group and Aggression x Age Group to our LDS model. In line with the recommendations of Cohen, Cohen, West, and Aiken (2003) to ease model interpretation, we mean-centered guilt and aggression before computing their interaction terms with age group (0 = 4-year-olds, 1 = 8-year-olds) and only retained significant interactions in the final model. When both interactions were included as predictors of children's dynamic SC and RSA, the LDS model showed good fit, χ^2 (64) = 83.62, p = .05, CFI = .99, TLI = .99, RMSEA = .04, 90% CI [.00, .06]. Guilt x Age Group significantly predicted ΔRSA[1] and ΔRSA[2] (b = .38, SE = .12, p = .001 and b = -.37, SE = .12, p = .003, respectively). We then dropped the nonsignificant interactions of Aggression x Age Group on SC and RSA, as well as the nonsignificant interaction of Guilt x Age Group on SC. Importantly, Guilt x Age Group was still a significant predictor of ΔRSA[1] and ΔRSA[2] (b = .35, SE = .11, p = .002 and b = -.35, SE = .12, p = .003, respectively) in this redefined LDS model, χ^2 (60) = 77.13, p =.07, CFI =.99, TLI = .99, RMSEA = .04, 90% CI [.00, .06] (depicted in Figure 3). In addition, accounting for these effects explained a significantly larger amount of variance in dynamic RSA than before (R^2 = .35 for ΔRSA[1] and R^2 = .60 for ΔRSA[2]).

Simple slopes analyses (Cohen et al., 2003) revealed that reporting a higher level of guilt was associated with a lesser decline in RSA from baseline to pretransgression (b = .19, SE = .07, p = .012) and a lesser increase in RSA from pretransgression to transgression (b = -.25, SE = .08,

p = .002) among 8-year-olds, but not 4-year-olds (b = -.16, SE = .08, p = .054 and b = .10, SE = .09, p = .267, respectively). The latter finding indicating sustained RSA withdrawal in response to the transgression portions—albeit for 8-year-olds only—was in line with our initial hypothesis. To aid the interpretation of these effects, Figure 4 depicts mean-level changes in observed RSA for 8-year-olds above and below the median for guilt. Finally, against our expectations, aggression was unrelated to children's dynamic SC and RSA regardless of age group (Table 4).

Discussion

ANS fluctuations in emotion-inducing situations prepare the body to mount an emotional response (Kreibig, 2010). Understanding children's expression and management of such physiology while they transgress may help explain why they feel more or less guilt after. We addressed this possibility in the present study. To account for a number of gaps endemic to developmental studies on the physiology of emotions, we assessed a) multiple ANS measures, b) the unfolding of such measures while children imagined themselves committing antisocial acts, c) possible extensions to caregiver-reported aggressive behavior, and d) developmental differences between 4- and 8-year-olds.

Among older children, we found that physiological patterns while transgressing systematically covaried with the intensity of guilt responses after transgressing. Guilt-prone children are thought to pay more attention to the morally salient aspects of transgressions (e.g., the victim), which highlights the negative consequences of such acts and likely triggers empathic and/or self-reflective processes that are part and parcel of guilt (Hoffman, 2000). The current findings suggest that children's expressions of guilt—and perhaps the attentional and evaluative processes that facilitate them—may be supported by a distinct pattern of physiological activity while transgressing. The nature of this pattern, discussed in the paragraphs to follow, may shed light on the regulatory mechanisms that give rise to guilt in childhood.

Although dynamic RSA was associated with guilt among 8-year-olds only, dynamic SC was unrelated to guilt regardless of age. This partially maps onto evidence for maturational increases in PNS influence. For example, Alkon and colleagues (2011) documented intraindividual increases in baseline RSA and baseline pre-ejection period (PEP) across the first 5 years of life (the latter indicative of less SNS activity; also see Hinnant et al., 2011). In the current study, this pattern was reflected cross-sectionally and extended into middle childhood, as 8-year-olds showed higher baseline RSA and lower baseline SC than 4-year-olds. Evidence for increases in PNS influence across childhood has been extended from resting to task-related ANS activity (e.g., Alkon et al., 2003), although studies accounting for age differences in SNS versus PNS influence on social-emotional outcomes are scarce (Hastings et al., 2014). The significance of dynamic RSA—relative to dynamic SC—for older children's guilt in our study may partially reflect maturational increases in PNS influence. Longitudinal studies are needed to reach a deeper understanding of how development factors into the differential ANS correlates of guilt.

The context of dynamic ANS activity should also be considered. Our experimental task (i.e., the SERT; Malti et al., 2009; Malti & Ongley, 2014) was designed to be socially challenging. According to polyvagal theory (Porges, 2011), the activity of the vagus nerve—indexed by RSA—is socially sensitive. Relatively primitive and isolated species (e.g., reptiles), which lack emotional expression and vocal communication, do not maintain a vagal brake on the heart. Vagal functioning is thought to have evolved alongside the need for mammals to communicate and cooperate. The vagus nerve can influence cardiac activity (i.e., increase and decrease HR) in lieu of a fight or flight SNS response, which is metabolically costly and undifferentiated by comparison (Kahle & Hastings, 2015). It also descends from the nucleus ambiguus alongside cranial nerves that govern key facets of socializing (e.g., head orienting, facial expressions, and vocal communication; Porges, 2011). Collectively, the efficiency and biological network of the vagal brake likely promote adaptive responses to the nuances of social engagements. This theorizing has received considerable support from studies documenting meaningful changes in RSA during social and emotional challenges (Beauchaine, 2001; Graziano & Derefinko, 2013). However, such studies rarely supplement RSA with additional biomarkers. In this regard, the current findings build on support for the social sensitivity of RSA by showing that changes in children's RSA, but *not* SC, were sensitive to their guilt—a prototypical social emotion (Malti, 2016).

Lastly, methodological issues related to SC may account for its nonassociations with guilt. Relative to other physiological measures, there are notable intraindividual differences in range of SC reactivity (i.e., a given change in microsiemens may be large for one person, but relatively small for another depending on their respective range/sensitivity). Correcting individuals' task SC reactivity for their own minimum and maximum SC (e.g., measured via separate baseline and stressor tests) has been shown to improve the predictive power of such scores (Lykken, Rose, Luther, & Mahey, 1966; for an alternative approach, see Ben-Shakhar, 1985). Attempts to replicate our findings should thus account for individual ranges in SC or use PEP (an index of heart contractility) as an alternative indicator of SNS activity.

We also investigated the role of dynamic ANS activity before versus during transgressions. Among 8-year-olds, changes in RSA from the baseline to pretransgression *and* pretransgression to transgression portions of our task were uniquely associated with the extent of their guilt feelings following the stories. This highlights the importance of using dynamic statistical and methodological approaches to account for the multifaceted components of children's social-emotional experiences as they unfold (including fluctuations *leading up to* conceptually critical events, such as transgressions; for a similar argument, see Kahle & Hastings, 2015).

From the baseline to pretransgression portions of the stories, children engaged with a desirable object (i.e., chocolate bar or lollipop). Although such objects would later become the focal point of a transgression, no transgression occurred at this stage. On average, children's RSA decreased to some extent when they were acquainted with the desirable objects (Table 3). Withdrawal of the vagal brake increases HR, which may have reflected positive affective arousal (e.g., happiness and excitement) in response to the chocolate bar and lollipop. Indeed, transient happiness has been associated with increases in HR secondary to vagal withdrawal (Harrison, Kreibig, & Critchley, 2013). Consistent with their blanketed trend of vagal withdrawal, 8-year-olds expressed a relatively strong preference for the desirable objects on average (i.e., 2.37 on a 3-point scale).

Nonetheless, more versus less guilty 8-year-olds showed systematically different RSA responses to the desirable objects (regardless of how much they preferred them). Those with lower or moderate levels of vagal withdrawal from baseline to the pretransgression portions reported higher levels of guilt after the stories (Figure 4). In other words, children with higher levels of guilt were *less* physiologically reactive to the desirable objects in the first place. This finding, which potentially reflects guiltier children's ability to harness their happiness in response to the desirable objects, nicely mirrors developmental literature on the ANS correlates of delay of gratification. Specifically, Wilson, Lengua, Tininenko, Taylor, and Trancik (2009) identified distinct physiological profiles for 8- to 11-year-olds who found it easy versus difficult to wait on a single, unknown prize for the later opportunity to select from a range of prizes. Children with low SC and *moderately high* HR reactivity were most likely to wait. By contrast, those who exhibited under- or over-arousal during the task were unable to wait (for related findings on the benefits of moderate versus excessive task-related vagal withdrawal, see Calkins, Graziano, & Keane, 2007; Kogan, Gruber, Shallcross, Ford, & Mauss, 2013; Marcovitch et al., 2010).

Delay of gratification tasks reliably tap into the construct of inhibitory control—the capacity to suppress a dominant, maladaptive response in favor of a nondominant, adaptive response (Kochanska, Murray, & Harlan, 2000). In the context of moral transgressions, higher inhibitory control may steer children away from dominant, immoral responses (e.g., stealing a desirable object), or at least help them consider the more nuanced, morally relevant consequences of such acts (a key ingredient of guilt; Hoffman, 2000). In support of this theorizing, Colasante, Zuffianò, Bae, and Malti (2014) found that children with higher levels of caregiver-reported inhibitory control were more likely to express guilt following hypothetical transgressions. The current study extends these findings to the biological level by showing that lower or relatively moderate RSA withdrawal in response to desirable objects—a physiological pattern consistent with greater inhibitory control (Wilson et al., 2009)—was associated with higher levels of guilt after transgressing to achieve those objects.

Eight-year-olds' dynamic RSA from the pretransgression to transgression portions of the stories (i.e., when they hypothetically stole from and harmed another child to achieve the chocolate bar and lollipop, respectively) was also associated with their guilt responses. On average, children's RSA increased during this portion (Table 3). However, as expected, those who reported more guilt tended to show little to no RSA increases, thus maintaining moderate levels of vagal withdrawal (Figure 4). In socially challenging situations, vagal withdrawal and associated increases in cardiac output allow the child to shift from internal homeostatic demands to environmental demands (Porges, 2011), and this ability has been linked to an array of positive developmental outcomes (e.g., fewer behavior problems and greater attentional/inhibitory control; Calkins & Keane, 2004; Calkins et al., 2007; Porges, Doussard-Roosevelt, Portales, & Greenspan, 1996; Suess, Porges, & Plude, 1994). Rather than reflecting sustained, residual happiness from the first portion of the stories, it is likely that moderate vagal withdrawal helped such children engage with morally salient aspects of the transgressions and evaluate their hypothetical actions (including how they violated moral principles and/or compromised the welfare of the victim).

On the other hand, children who reported little or no guilt tended to show RSA recovery toward their baseline level while transgressing. Increased RSA, or vagal augmentation, may reflect a failure to engage with environmental demands (Calkins & Dedmon, 2000). Disproportionately high levels of vagal withdrawal in response to the desirable objects at pretransgression may have disrupted such children's ability to engage with the following transgression portions (i.e., maintain RSA withdrawal) and thereby employ the requisite cognitive resources to mount an adaptive guilt response (see Malti, 2016; Malti et al., 2017). In line with this explanation, excessive physiological reactivity is theorized to interfere with the effective allocation of executive functions to meet task demands (Wilson & Gottman, 1996) and has been linked to poorer performance on challenging experimental tasks (Marcovitch et al., 2010). Conversely, vagal augmentation may have indicated an attempt to return to calm (Porges, 2011). At this portion of the story, it was visually apparent that the child had the desirable object in his or her hand (Figure 1)—so less guilty children may have simply been relieved.

Accordingly, they may have perceived the situation as resolved, disengaged from the transgression in question, and pressed the vagal brake in an attempt to return to a resting—perhaps indulgent—state.

We also explored links between ANS activity and aggressive behavior. As expected and in line with previous findings (Colasante et al., 2016; Malti & Krettenauer, 2013; Stuewig et al., 2015), 8-year-olds who reported higher levels of guilt were rated lower in dispositional aggressive behavior by their caregivers (the same trend was apparent in 4-year-olds, but did not reach significance). In contrast to our hypotheses, children's ANS activity was not associated with their aggression. Dynamic RSA may have been indirectly related to aggression through its significant links to guilt. Our conceptual focus and statistical model, however, were centered on physiological patterns as endogenous variables and, as a result, did not emphasize/support the testing of indirect physiology–emotion–behavior links. Nonetheless, our results are encouraging for future researchers who wish to investigate such pathways.

Why was RSA activity associated with guilt reports for 8-year-olds but not 4-year-olds? The rarity of longitudinal studies linking physiology to social emotions makes it difficult to generate meaningful age-graded hypotheses (Hastings et al., 2014). However, it could be that links between physiology and social emotions become increasingly coordinated as the latter become increasingly internalized. Guilt and its corresponding process of internalization develop later in childhood than other social emotions, such as empathy and sympathy (Malti, 2016; Malti et al., 2017). From this perspective, the synchrony of children's physiological and expressed guilt responses may serve as a proxy of their internalization and could thus be studied longitudinally to gain a better understanding of normative trends in this critical developmental process. Furthermore, 4-year-olds had fewer and less variable guilt responses than 8-year-olds

(Table 1). Although this aligns with well-established developmental increases in expressions of guilt from early to middle childhood (Arsenio, 2014; Malti & Ongley, 2014), it also highlights the task for future researchers to design paradigms that may be more sensitive to the physiological correlates of guilt's early manifestations or precursors.

In addition to the limitations noted throughout this discussion, it is important to consider generalizability. Although we made significant efforts to immerse children and designed our vignettes to represent common day-to-day transgressions, they were nonetheless hypothetical and the degree to which our results generalize to actual transgressions is unclear. Even though children's reports of guilt following the transgressions were linked to caregiver reports of actual behavior (attesting to external validity), the intensity and/or pattern of their physiological activity may have been different if actual transgressions were assessed.

The biological processes that underpin guilt—which have been largely untapped to date—may serve as a promising window into the mechanisms behind such feelings. In sum, our findings suggest that children's ANS reactions leading up to and during transgressions prepare them to process morally salient information and thereby mount a guilt response afterward. Future studies should employ an even more diverse array of physiological measures (e.g., PEP), longitudinal assessments, and differential statistical procedures (e.g., mediational analyses) to shed further light on the interplay of physiology, guilt, and aggressive behavior across childhood.

Table 1

Descriptive Statistics by Age Group

	4-year-olds	8-year-olds
	M (*SD*)	*M* (*SD*)
Guilt	0.65 (0.99)	1.97 (1.14)
SC		
Baseline	18.96 (7.68)	14.97 (5.42)
Pretransgression	20.68 (7.28)	16.97 (5.89)
Transgression	20.25 (7.24)	16.68 (5.85)
RSA		
Baseline	6.52 (1.11)	7.01 (1.13)
Pretransgression	6.14 (1.17)	6.55 (1.16)
Transgression	6.32 (1.18)	6.71 (1.16)
Aggression	1.50 (0.72)	0.96 (0.74)
Preference	2.80 (0.51)	2.37 (0.61)

Note. Guilt (child reported; range = 0–3). SC (skin conductance in microsiemens). RSA (respiratory sinus arrhythmia). Aggression (caregiver reported; range = 0–6). Preference (i.e., liking of desirable objects from stories; child reported; range = 0–3). Guilt, SC, RSA, and preference scores averaged across stories (where applicable).

Table 2

Zero-Order Correlations by Age Group

	1	2	3	4	5	6	7	8	9	10	11
1. Guilt	—	.00	-.01	.00	-.10	.09	-.15	-.20*	.17	-.14	.01
2. SC (B)	.06	—	.91***	.91***	.01	-.08	.06	-.03	-.02	.06	-.09
3. SC (P)	.05	.92***	—	.99***	.02	-.12	.03	-.09	.11	.03	-.06
4. SC (T)	.05	.92***	.99***	—	.00	-.13	.03	-.08	.11	.03	-.06
5. RSA (B)	.06	-.11	-.13	-.13	—	.73***	.78***	-.14	.15	.07	-.11
6. RSA (P)	-.10	-.15	-.18	-.17	.65***	—	.74***	-.03	.03	-.05	-.14
7. RSA (T)	-.04	-.15	-.23*	-.21	.76***	.70***	—	-.01	.08	.00	-.21*
8. Aggression	-.18	-.15	-.15	-.16	.12	.16	.19	—	-.25**	.01	.20*
9. Preference	-.08	.06	-.02	-.01	-.16	-.07	-.18	.02	—	.00	-.24*
10. Gender	-.01	.06	-.04	-.02	.00	.13	.01	.08	-.12	—	.12
11. SES	.02	-.24*	-.19	-.18	.15	.13	.12	-.07	-.11	.08	—

Note. Lower half = 4-year-olds, upper half = 8-year-olds. SC (skin conductance). RSA (respiratory sinus arrhythmia). B (baseline). P (pretransgression). T (transgression). Gender (girls = 1, boys = 2). SES (socioeconomic status [i.e., caregiver's highest level of education]; 1 = no diploma, 7 = doctoral degree). Guilt, SC, RSA, and preference scores averaged across stories (where applicable). $^{***}p < .001$. $^{**}p < .01$. $^{*}p < .05$.

Table 3

Unconditional LDS Models for SC and RSA

	M	Variance
SC[1]	16.71^{*} (.49)	44.53^{*} (5.68)
Δ*SC*[1]	2.07^{*} (.20)	6.17^{*} (.78)
Δ*SC*[2]	$-.35^{*}$ (.03)	0.04 (.04)
RSA[1]	6.82^{*} (.08)	1.32^{*} (.14)
Δ*RSA*[1]	$-.45^{*}$ (.06)	0.37^{*} (.08)
Δ*RSA*[2]	$.16^{*}$ (.06)	0.11 (.10)

Note. Estimated means and variances with their standard errors (in parentheses). $^{*}p < .05$. *SC*[1]/*RSA*[1] (latent baseline skin conductance/respiratory sinus arrhythmia). Δ*SC*[1]/Δ*RSA*[1] (latent skin conductance/respiratory sinus arrhythmia change score from baseline to pretransgression). Δ*SC*[2]/Δ*RSA*[2] (latent skin conductance/respiratory sinus arrhythmia change score from pretransgression to transgression).

Table 4

Conditional Bivariate LDS Model for SC and RSA

	SC[1]	Δ*SC*[1]	Δ*SC*[2]	*RSA*[1]	Δ*RSA*[1]	Δ*RSA*[2]
Guilt	.17 (.47), p = .72	-.04 (.17), p = .80	.04 (.03), p = .19	-.02 (.08), p = .78	-.16 (.08), p = .05	.10 (.09), p = .27
Aggression	-.90 (.63), p = .15	.03 (.36), p = .94	.06 (.05), p = .25	-.04 (.12), p = .77	-.05 (.16), p = .74	-.04 (.09), p = .63
Age group	-4.80 (1.31), p < .001	.27 (.62), p = .67	.17 (.09), p = .06	.54 (.24), p = .03	.07 (.08), p = .39	.07 (.17), p = .67
Guilt x Age Group	—	—	—	—	.35 (.11), p < .01	-.35 (.12), p < .01
Preference	-.32 (.92), p = .72	.68 (.43), p = .11	.10 (.06), p = .08	-.32 (.92), p = .72	-.06 (.12), p = .61	.08 (.12), p = .53
Gender	.74 (.96), p = .44	-.63 (.40), p = .11	.10 (.07), p = .12	.11 (.17), p = .51	.01 (.12), p = .98	-.05 (.13), p = .72
SES	-.95 (.44), p = .03	.20 (.21), p = .34	-.01 (.03), p = .82	.01 (.08), p = .98	-.07 (.06), p = .26	-.01 (.07), p = .91

Note. Unstandardized beta coefficients with their standard errors (in parentheses) and *p* values.

Figure 1. Visuals for the pretransgression (left) and transgression (right) portions of the a) chocolate bar story and b) lollipop story.

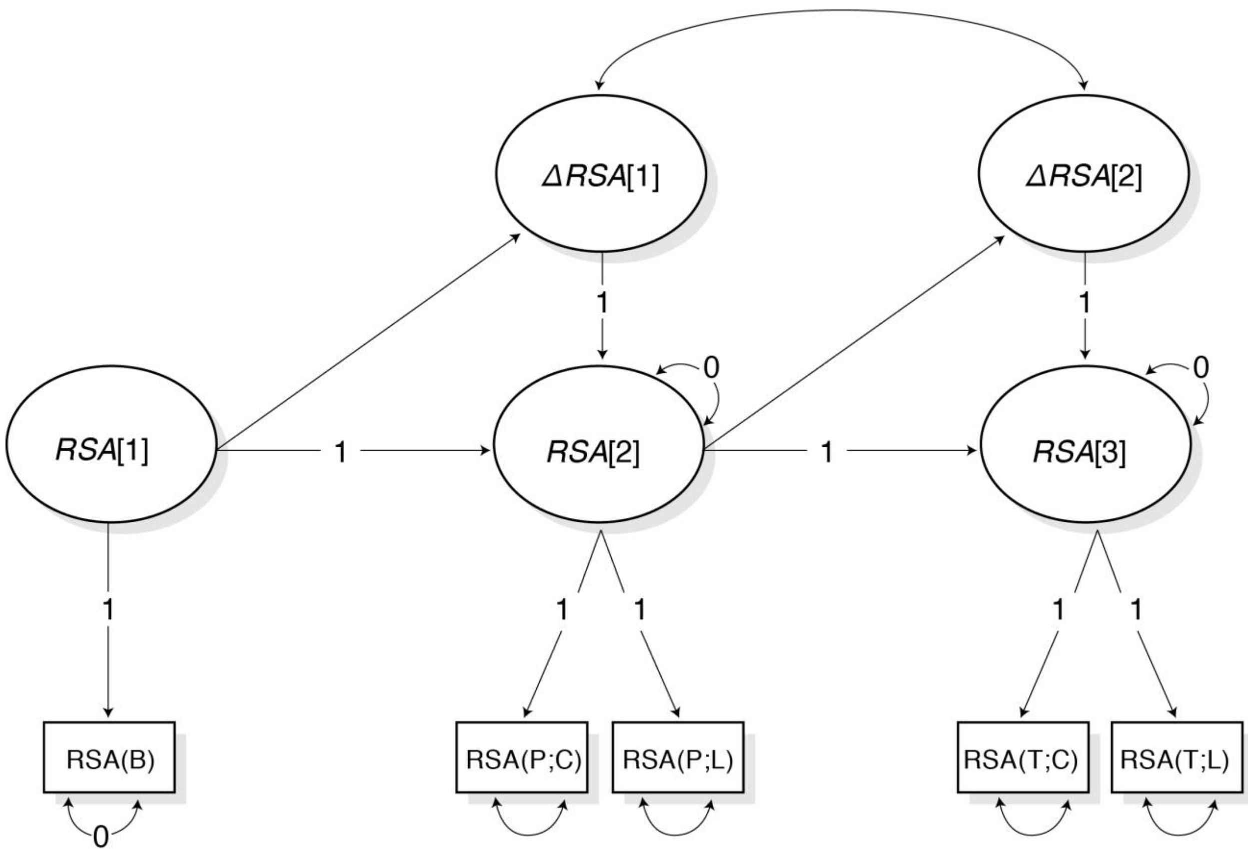

Figure 2. Unconditional LDS model for RSA.
Note. RSA (respiratory sinus arrhythmia). B (baseline). P (pretransgression). T (transgression). C (chocolate bar story). L (lollipop story).

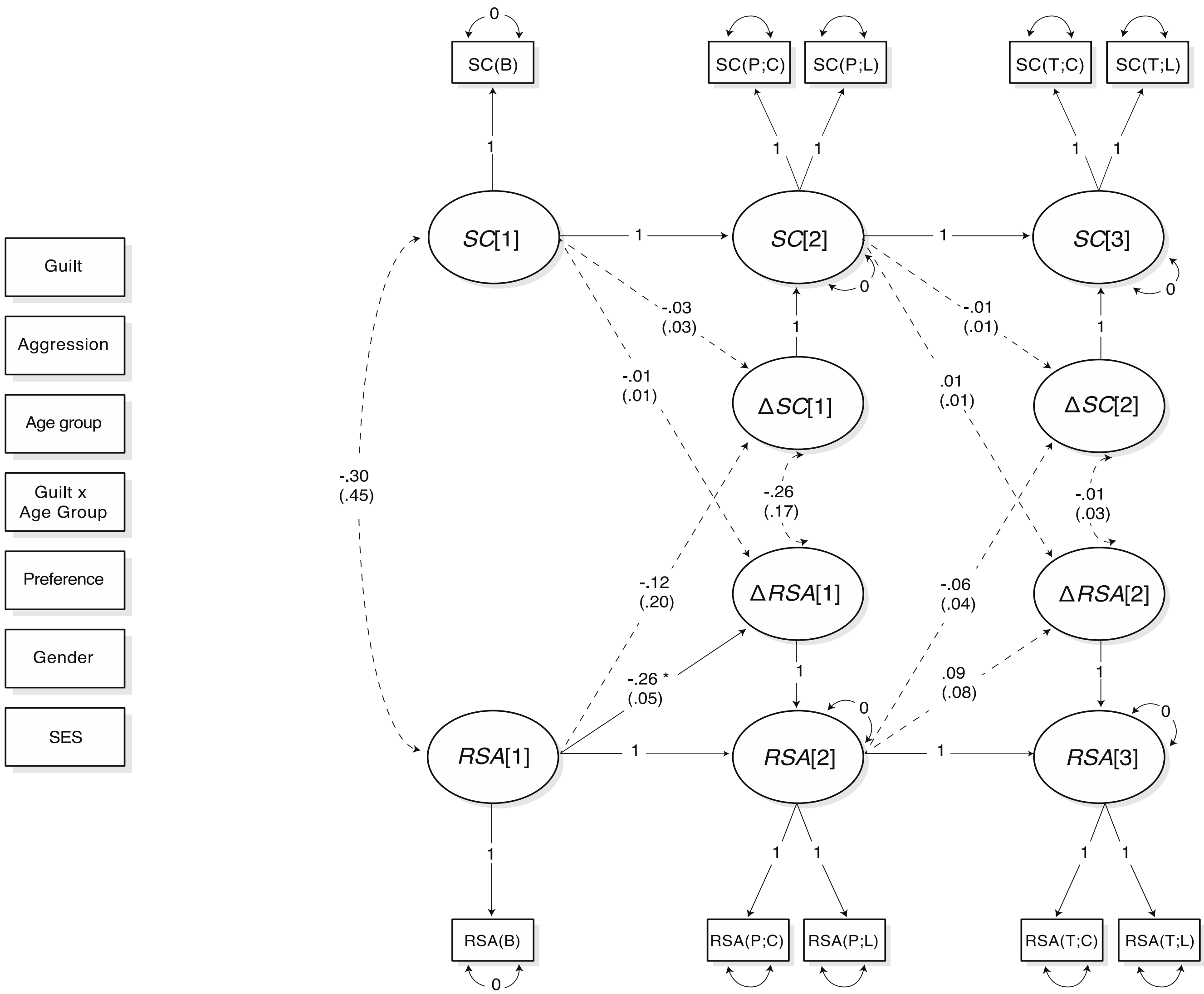

Figure 3. Conditional bivariate LDS model for SC and RSA predicted from guilt, aggression, age group, and control variables.
Note. Unstandardized parameters with their standard errors (in parentheses). Dotted lines represent nonsignificant paths ($p > .05$). For the sake of simplicity, the effects of observed variables (on left of figure) are reported in Table 4. $^{*}p < .05$.

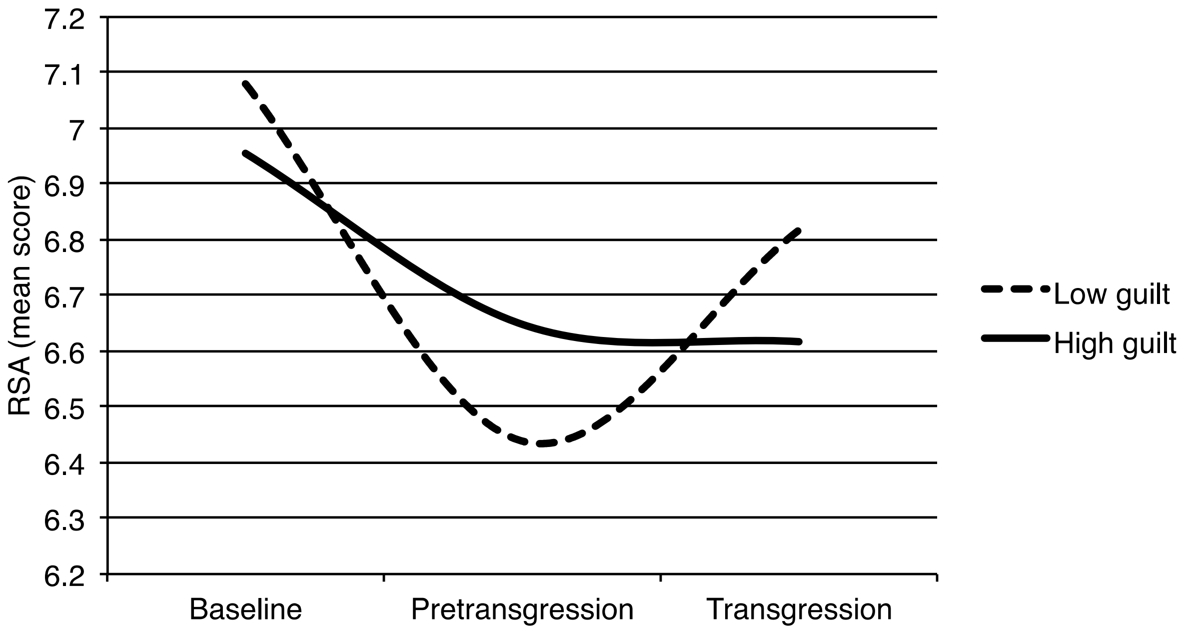

Figure 4. Mean-level changes in observed RSA across the task intervals for 8-year-olds above and below the median for guilt.

References

Achenbach, T. M., & Rescorla, L. A. (2000). *Manual for the ASEBA preschool forms & profiles*. Burlington, VT: University of Vermont, Research Center for Children, Youth, & Families.

Achenbach, T. M., & Rescorla, L. A. (2001). *Manual for the ASEBA school-age forms & profiles*. Burlington, VT: University of Vermont, Research Center for Children, Youth, & Families.

Alkon, A., Boyce, W. T., Davis, N. V., & Eskenazi, B. (2011). Developmental changes in autonomic nervous system resting and reactivity measures in Latino children from 6 to 60 months of age. *Journal of Developmental and Behavioral Pediatrics, 32*(9), 668–677. doi:10.1097/DBP.0b013e3182331fa6

Alkon, A., Goldstein, L. H., Smider, N., Essex, M. J., Kupfer, D. J., & Boyce, W. T. (2003). Developmental and contextual influences on autonomic reactivity in young children. *Developmental Psychobiology, 42*(1), 64–78. doi:10.1002/dev.10082

Anastassiou-Hadjicharalambous, X., & Warden, D. (2007). Convergence between physiological, facial and verbal self-report measures of affective empathy in children. *Infant and Child Development, 16*(3), 237–254. doi:10.1002/icd.464

Arsenio, W. (2014). Moral emotion attributions and aggression. In M. Killen & J. Smetana (Eds.), *Handbook of moral development* (2nd ed., pp. 235–255). New York, NY: Psychology Press.

Baker, E., Baibazarova, E., Ktistaki, G., Shelton, K. H., & van Goozen, Stephanie H. M. (2012). Development of fear and guilt in young children: Stability over time and relations with psychology. *Development and Psychopathology, 24*(3), 833–845. doi:10.1017/S0954579412000399

Barhight, L. R., Hubbard, J. A., & Hyde, C. T. (2013). Children's physiological and emotional reactions to witnessing bullying predict bystander intervention. *Child Development, 84*(1), 375–390. doi:10.1111/j.1467-8624.2012.01839.x

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. doi:10.1017/S0954579401002012

Ben-Shakhar, G. (1985). Standardization within individuals: A simple method to neutralize individual differences in skin conductance. *Psychophysiology, 22*(3), 292–299. doi:10.1111/j.1469-8986.1985.tb01603.x

Bradley, M. M., & Lang, P. J. (2007). Emotion and motivation. In J. T. Cacioppo, L. G. Tassinary, & G. Berntson (Eds.), *Handbook of psychophysiology* (3rd ed., pp. 581–607). New York, NY: Cambridge University Press.

Burt, K. B., & Obradović, J. (2013). The construct of psychophysiological reactivity: Statistical and psychometric issues. *Developmental Review, 33*(1), 29–57. doi:10.1016/j.dr.2012.10.002

Cacioppo, J. T., & Sandman, C. A. (1978). Physiological differentiation of sensory and cognitive tasks as a function of warning, processing demands, and reported unpleasantness. *Biological Psychology, 6*(3), 181–192. doi:10.1016/0301-0511(78)90020-0

Calkins, S. D., & Dedmon, S. E. (2000). Physiological and behavioral regulation in two-year-old children with aggressive/destructive behavior problems. *Journal of Abnormal Child Psychology, 28*(2), 103–118. doi:10.1023/A:1005112912906

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. doi:10.1016/j.biopsycho.2006.09.005

Calkins, S. D., & Keane, S. P. (2004). Cardiac vagal regulation across the preschool period: Stability, continuity, and implications for childhood adjustment. *Developmental Psychobiology, 45*(3), 101–112. doi:10.1002/dev.20020

Cannon, W.B., 1927. The James-Lange theory of emotions: A critical examination and an alternative theory. *American Journal of Psychology*, *39*, 106–124. doi:10.2307/1415404

Cohen, J., Cohen, P., West, S. G., & Aiken, L. S. (2003). *Applied multiple regression/correlation analysis for the behavioural sciences* (3rd ed.). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Colasante, T., Zuffianò, A., Bae, N. Y., & Malti, T. (2014). Inhibitory control and moral emotions: Relations to reparation in early and middle childhood. *The Journal of Genetic Psychology: Research and Theory on Human Development, 175*(6), 511–527. doi:10.1080/00221325.2014.976535

Colasante, T., Zuffianò, A., & Malti, T. (2016). Daily deviations in anger, guilt, and sympathy: A developmental diary study of aggression. *Journal of Abnormal Child Psychology*, *44*(8), 1515–1526. doi:10.1007/s10802-016-0143-y

Cui, L., Morris, A. S., Harrist, A. W., Larzelere, R. E., Criss, M. M., & Houltberg, B. J. (2015). Adolescent RSA responses during an anger discussion task: Relations to emotion regulation and adjustment. *Emotion, 15*(3), 360–372. doi:10.1037/emo0000040

Dawson, M. E., Schell, A. M., & Filion, D. L. (2007). The electrodermal system. In J. T. Cacioppo, L. G. Tassinary & G. G. Berntson (Eds.), *Handbook of psychophysiology* (3rd ed., pp. 159–181). New York, NY: Cambridge University Press. doi:10.1017/CBO9780511546396.007

Eisenberg, N., Fabes, R. A., Carlo, G., Troyer, D., Speer, A. L., Karbon, M., Switzer, G. (1992). The relations of maternal practices and characteristics to children's vicarious emotional responsiveness. *Child Development*, *63*(3), 583–602. doi:10.2307/1131348

Eisenberg, N., Fabes, R. A., Miller, P. A., Fultz, J., Shell, R., Mathy, R. M., & Reno, R. (1989). Relation of sympathy and personal distress to prosocial behavior: A multimethod study. *Journal of Personality and Social Psychology*, *57*(1), 55–66. doi:10.1037/0022-3514.57.1.55

Eisenberg, N., Fabes, R., Miller, P., Shell, R., Shea, C., & May-Plumlee, T. (1990). Preschoolers' vicarious emotional responding and their situation and dispositional prosocial behaviour. *Merrill-Palmer Quarterly*, *36*(4), 507–529.

Eisenberg, N., Fabes, R. A., Schaller, M., Carlo, G., & Miller, P. A. (1991). The relations of parental characteristics and practices to children's vicarious emotional responding. *Child Development*, *62*(6), 1393–1408. doi:10.2307/1130814

Eisenberg, N., Spinrad, T. L., & Eggum, N. D. (2010). Emotion-related self-regulation and its relation to children's maladjustment. *Annual Review of Clinical Psychology*, *6*, 495–525. doi:10.1146/annurev.clinpsy.121208.131208

Field, A. P., & Schorah, H. (2007). The verbal information pathway to fear and heart rate changes in children. *Journal of Child Psychology and Psychiatry, 48*(11), 1088–1093. doi:10.1111/j.1469-7610.2007.01772.x

Fourie, M. M., Rauch, H. G. L., Morgan, B. E., Ellis, G. F. R., Jordaan, E. R., & Thomas, K. G. F. (2011). Guilt and pride are heartfelt, but not equally so. *Psychophysiology, 48*(7), 888–899. doi:10.1111/j.1469-8986.2010.01157.x

Freud, S. (1994). *Civilization and its discontents* (J. Riviere, Trans.). In S. Appelbaum & T. Crofts (Eds.), *Civilization and its discontents*. Mineola, NY: Dover Publications. (Original work published 1930)

Frick, P. J., Kimonis, E. R., Dandreaux, D. M., & Farell, J. M. (2003). The 4-year stability of psychopathic traits in non-referred youth. *Behavioral Sciences & the Law, 21*(6), 713–736. doi:10.1002/bsl.568

Graziano, P., & Derefinko, K. (2013). Cardiac vagal control and children's adaptive functioning: A meta-analysis. *Biological Psychology, 94*(1), 22–37. doi:10.1016/j.biopsycho.2013.04.011

Harrison, N. A., Kreibig, S. D., & Critchley, H. D. (2013). A two-way road: Efferent and afferent pathways of autonomic activity in emotion. In J. Armony & P. Vuilleumier (Eds.), *The Cambridge handbook of human affective neuroscience* (pp. 82–106). Cambridge, UK: Cambridge University Press.

Hastings, P. D., Miller, J. G., Kahle, S., & Zahn-Waxler, C. (2014). The neurobiological bases of empathic concern for others. In M. Killen & J. G. Smetana (Eds.), *Handbook of moral development* (2nd ed., pp. 411–434). Mahwah, NJ: Lawrence Erlbaum Associates, Inc. doi:10.4324/ 9780203581957.ch19

Hinnant, J. B., Elmore-Staton, L., & El-Sheikh, M. (2011). Developmental trajectories of respiratory sinus arrythmia and preejection period in middle childhood. *Developmental Psychobiology, 53*(1), 59–68. doi:10.1002/dev.20487

Hoffman, M. L. (2000). *Empathy and moral development: Implications for caring and justice*. New York, NY: Cambridge University Press.

Kahle, S. S., & Hastings, P. D. (2015). The neurobiology and physiology of emotions: A developmental perspective. In R. A. Scott, S. M. Kosslyn, & N. Pinkerton (Eds.), *Emerging trends in the social and behavioral sciences: An interdisciplinary, searchable, and linkable resource.* Hoboken, NJ: John Wiley. doi:10.1002/9781118900772.etrds0237

Kline, R. B. (2016). *Principles and practice of structural equation modeling* (4th ed.). New York, NY: Guilford Press.

Kochanska, G., Gross, J. N., Lin, M., & Nichols, K. E. (2002). Guilt in young children: Development, determinants, and relations with a broader system of standards. *Child Development*, *73*, 461–482. doi:10.1111/1467-8624.00418

Kochanska, G., Murray, K. T., & Harlan, E. T. (2000). Effortful control in early childhood: Continuity and change, antecedents, and implications for social development. *Developmental Psychology*, *36*(2), 220–232. doi:10.1037/0012-1649.36.2.220

Kogan, A., Gruber, J., Shallcross, A. J., Ford, B. Q., & Mauss, I. B. (2013). Too much of a good thing? Cardiac vagal tone's nonlinear relationship with well-being. *Emotion, 13*(4), 599–604. doi:10.1037/a0032725

Kreibig, S. D. (2010). Autonomic nervous system activity in emotion: A review. *Biological Psychology, 84*(3), 394–421. doi:10.1016/j.biopsycho.2010.03.010

Lansink, J. M., & Richards, J. E. (1997). Heart rate and behavioral measures of attention in six-, nine-, and twelve-month-old infants during object exploration. *Child Development*, *68*, 610–620. doi:10.1111/j.1467-8624.1997.tb04224.x.

Lewis, M., Ramsay, D. S., & Sullivan, M. W. (2006). The relation of ANS and HPA activation to infant anger and sadness response to goal blockage. *Developmental Psychobiology*, *48*(5), 397–405. doi:10.1002/dev.20151

Lorber, M. F. (2004). Psychophysiology of aggression, psychopathy, and conduct problems: A meta-analysis. *Psychological Bulletin*, *130*(4), 531–552. doi:10.1037/0033-2909.130.4.531

Ludwig, J., Duncan, G. J., & Hirschfield, P. (2001). Urban poverty and juvenile crime: Evidence from a randomized housing-mobility experiment. *Quarterly Journal of Economics, 116*, 655–680. doi:10.1162/00335530151144122

Lykken, D. T., Rose, R. J., Luther, B., & Mahey, M. (1966). Correcting psychophysiological measures for individual differences in range. *Psychological Bulletin, 66*, 481–484.

Malti, T. (2016). Toward an integrated clinical-developmental model of guilt. *Developmental Review*, *39*, 16–36. doi:10.1016/j.dr.2015.11.001

Malti, T., Dys, S. P., Colasante, T., & Peplak, J. (in press). Emotions and morality: New developmental perspectives. In C. Helwig (Ed.), *New perspectives on moral development*. New York, NY: Psychology Press.

Malti, T., Gummerum, M., Keller, M., & Buchmann, M. (2009). Children's moral motivation, sympathy, and prosocial behavior. *Child Development, 80*(2), 442–460. doi:10.1111/j.1467-8624.2009.01271.x

Malti, T. & Krettenauer, T. (2013). The relation of moral emotion attributions to prosocial and antisocial behavior: A meta-analysis. *Child Development, 84*(2), 397–412. doi:10.1111/j.1467-8624.2012.01851.x

Malti, T., & Ongley, S. (2014). The development of moral emotions and moral reasoning. In M. Killen & J. Smetana (Eds.), *Handbook of moral development* (2nd ed., pp. 163–183). New York, NY: Psychology Press.

Marcovitch, S., Leigh, J., Calkins, S. D., Leerks, E. M., O'Brien, M., & Nayena Blankson, A. (2010). Moderate vagal withdrawal in 3.5-year-old children is associated with optimal performance on executive function tasks. *Developmental Psychobiology, 52*(6), 603–608. doi:10.1002/dev.20462

McArdle, J. J. (2009). Latent variable modeling of differences and changes with longitudinal data. *Annual Review of Psychology, 60*, 577–605. doi:10.1146/annurev.psych.60.110707.163612

Miller, J. G., Kahle, S., & Hastings, P. D. (2015). Roots and benefits of costly giving: Children who are more altruistic have greater autonomic flexibility and less family wealth. *Psychological Science*, *26*(7), 1038–1045. doi:10.1177/0956797615578476

Miller, J. G., Nuselovici, J. N., & Hastings, P. D. (2016). Nonrandom acts of kindness: Parasympathetic and subjective empathic responses to sadness predict children's prosociality. *Child Development*, *87*(6), 1679–1690. doi:10.1111/cdev.12629

Miller, B. D., & Wood, B. L. (1997). Influence of specific emotional states on autonomic reactivity and pulmonary function in asthmatic children. *Journal of the American Academy of Child & Adolescent Psychiatry, 36*(5), 669–677. doi:10.1097/00004583-199705000-00018

Moors, A. (2009). Theories of emotion causation: A review. *Cognition and Emotion, 23*(4), 625–662. doi:10.1080/02699930802645739

Muthén, L., & Muthén, B. (2012). *Mplus user's guide*. Los Angeles, CA: Muthén & Muthén.

Nivette, A. E., Eisner, M., Malti, T., & Ribeaud, D. (2014). Sex differences in aggression among children of low and high gender inequality backgrounds: A comparison of gender role and sexual selection theories. *Aggressive Behavior, 40*, 451–464. doi:10.1002/ab.21530

Nunner-Winkler, G., & Sodian, B. (1988). Children's understanding of moral emotions. *Child Development, 59*(5), 1323–1328. doi:10.2307/1130495

Obradović, J., Bush, N. R., Stamperdahl, J., Adler, N. E., & Boyce, W. T. (2010). Biological sensitivity to context: The interactive effects of stress reactivity and family adversity on socioemotional behavior and school readiness. *Child Development, 81*(1), 270–289. doi:10.1111/j.1467-8624.2009.01394.x

Ongley, S. F., & Malti, T. (2014). The role of moral emotions in the development of children's sharing behavior. *Developmental Psychology, 50*(4), 1148–1159. doi:10.1037/a0035191

Porges, S. W. (2011). *The polyvagal theory: Neurophysiological foundations of emotions, attachment, communication, and self-regulation*. New York, NY: W. W. Norton & Co.

Porges, S. W., Doussard-Roosevelt, J., Portales, A. L., & Greenspan, S. I. (1996). Infant regulation of the vagal "brake" predicts child behavior problems: A psychobiological model of social behavior. *Developmental Psychobiology*, *29*(8), 697–712. doi:10.1002/(SICI)1098-2302(199612)29:8

Richards, J. E., & Cronise, K. (2000). Extended visual fixation in the early preschool years: Look duration, heart rate changes, and attentional inertia. *Child Development*, *71*, 602–620. doi:10.1111/1467-8624.00170.

Scherer, K. R. (2009). The dynamic architecture of emotion: Evidence for the component process model. *Cognition and Emotion, 23*(7), 1307–1351. doi:10.1080/02699930902928969

Statistics Canada. (2013). *NHS profile, Mississauga, CY, Ontario, 2011*. (Catalogue number 99-004-XWE). Retrieved from the Statistics Canada website: http://www12.statcan.gc.ca/nhs-enm/2011/dp-pd/prof/index.cfm?Lang=E

Stuewig, J., Tangney, J. P., Kendall, S., Folk, J. B., Meyer, C. R., & Dearing, R. L. (2015). Children's proneness to shame and guilt predict risky and illegal behaviors in young adulthood. *Child Psychiatry and Human Development, 46*(2), 217–227. doi:10.1007/s10578-014-0467-1

Suess, P. E., Porges, S. W., & Plude, D. J. (1994). Cardiac vagal tone and sustained attention in school-age children. *Psychophysiology, 31*(1), 17–22. doi:10.1111/j.1469-8986.1994.tb01020.x

Tangney, J. P., Stuewig, J., & Mashek, D. J. (2007). Moral emotions and moral behavior. *Annual Review of Psychology, 58*, 345–372. doi:10.1146/annurev.psych.56.091103.070145

Tracy, J. L., Robins, R. W., & Lagattuta, K. H. (2005). Can children recognize pride? *Emotion, 5*, 251–257. doi:10.1037/1528-3542.5.3.251

Turiel, E. (1983). *The development of social knowledge: Morality and convention*. New York, NY: Cambridge University Press.

Weems, C. F., Zakem, A. H., Costa, N. M., Cannon, M. F., & Watts, S. E. (2005). Physiological response and childhood anxiety: Association with symptoms of anxiety disorders and cognitive bias. *Journal of Clinical Child and Adolescent Psychology, 34*(4), 712–723. doi:10.1207/s15374424jccp3404_13

Wilson, B. J., & Gottman, J. M. (1996). Attention—the shuttle between emotion and cognition: Risk, resiliency, and physiological bases. In E. M. Hetherington, & E. A. Blechman

(Eds.), *Stress, coping, and resiliency in children and families* (pp. 189–228). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Wilson, A. C., Lengua, L. J., Tininenko, J., Taylor, A., & Trancik, A. (2009). Physiological profiles during delay of gratification: Associations with emotionality, self-regulation, and adjustment problems. *Journal of Applied Developmental Psychology, 30*(6), 780–790. doi:10.1016/j.appdev.2009.05.002

Zahn-Waxler, C., Cole, P. M., Welsh, J. D., & Fox, N. A. (1995). Psychophysiological correlates of empathy and prosocial behaviors in preschool children with behavior problems. *Development and Psychopathology*, *7*(1), 27–48. doi:10.1017/S0954579400006325