CHILD DEVELOPMENT

Child Development, xxxx 2021, Volume 00, Number 0, Pages 1–17

Exclusion Expected? Cardiac Slowing Upon Peer Exclusion Links Preschool Parent Representations to School-Age Peer Relationships

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Attachment theory proposes that children's representations of interactions with caregivers guide information-processing about others, bridging interpersonal domains. In a longitudinal study (N = 165), preschoolers (M_{age} = 5.19 years) completed the MacArthur Story Stem Battery to assess parent representations. At school-age (M_{age} = 8.42 years), children played a virtual ballgame with peers who eventually excluded them to track event-related cardiac slowing, a physiological correlate of rejection, especially when unexpected. At both ages, parents and teachers reported on peer and emotional problems. During exclusion versus inclusion-related events, cardiac slowing was associated with greater positive parent representations and fewer emerging peer problems. Cardiac slowing served as a mediator between positive parent representations and peer problems, supporting a potential psychophysiological mechanism underlying the generalization of attachment-related representations to peer relationships.

"An unwanted child is likely not only to feel unwanted by his parents, but to believe that he is essentially unwantable, namely unwanted by anyone" (Bowlby, 1973, p. 204).

How caregivers relate to children affects how children relate to others. Ample work confirms a robust effect of child–parent attachment on peer relationships (Groh, Fearon, van Ijzendoorn, Bakermans-Kranenburg, & Roisman, 2017). Yet, the issue of *why* these social domains inter-relate is less often subjected to empirical scrutiny (Thompson, 2016). Many theories assume that children internalize repeated interactions with caregivers, forming representations or *internal working models* helping them to make sense and predict the future course of interpersonal exchanges (e.g., Bowlby, 1973; Stern, 1985). Looking time studies indeed suggest that

Annette M. Klein and Kai von Klitzing shared senior authorship. We are grateful to Robert N. Emde for helpful comments on an earlier draft. The authors would like to thank all families for taking part and the Public Health Department of the City of Leipzig for cooperating in this study. Grants of the German Research Foundation (DFG) to Kai von Klitzing and Annette M. Klein (Grants KL 2315/1-1, KL2315/1-2 and KL 2338/1-2) and the Federal Ministry of Education and Research (BMBF) to Kai von Klitzing, Lars O. White, and Annette M. Klein (01KR1201A and 01KR1802A) supported this research.

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0009-3920/2021/xxxx-xxxx
DOI: 10.1111/cdev.13494

infants already possess representations of relationships to their caregivers, showing that insecurely attached infants look longer at displays of responsive versus unresponsive parenting, indicating greater expectancy violation, whereas securely attached infants show the reverse pattern (e.g., Johnson, Dweck, & Chen, 2007).

While intriguing, these findings do not speak to the key notion that children generalize their internal representations of child–caregiver bonds to the broader social sphere, impacting future relations, potentially even “despite the absence of fit” (Bowlby, 1988, p. 170). A caregiver who is available and responsive to the child’s needs, is thought to impart positive social expectations, the give-and-take nature of interpersonal relationships and empathic relating (“reciprocity”), as well as self-worth and self-efficacy, resulting in more confident and competent behavior toward others (Elicker, Englund, & Sroufe, 1992). Scholars have labeled this the “competence hypothesis” which is thought to lie at “the core of attachment theory” (van Ijzendoorn, 1990, p. 7). The notion of generalization of representations is often invoked to explain the link between a child’s behavioral attachment pattern and social relations with peers, which exists irrespective of child-age or time-lag between assessments of attachment and peer domains (Groh et al., 2017).

Evidence for the possible role of child representations in this process emanates from work using narrative story-completions to tap into children’s representations. Thus, children who narrate stories with more supportive and nurturing parent characters behave more prosocially or less antisocially toward others (Oppenheim, Emde, & Warren, 1997; Page & Bretherton, 2001; Stadelmann, Perren, von Wyl, & von Klitzing, 2007). Typically, such findings are offered as evidence for the idea that children perceive and interact with others as a function of their internal representations. Physiological data, reflecting expectation-based processes assessed in real-time social interactions would arguably further buttress this idea.

Yet, to date, few studies probe the physiological basis of generalization of representations, especially in child samples (Bretherton & Munholland, 2016; Long, Verbeke, Ein-Dor, & Vrtička, 2020). Instead, most work in this area focuses on behavioral, cognitive, and self-report measures (see Dykas & Cassidy, 2011). This work indicates that compared to their securely attached counterparts, insecurely attached children make more hostile or fewer benign motivational attributions in peer vignettes and show less support-seeking, more often reciprocating hostility during peer interactions (Thompson, 2016).

While valuable, some important aspects of how representations are thought to exert their influence in new social encounters may remain untapped by overt measures. For example, avoidantly attached individuals tend to under-report or inhibit outward expression of distress evident on physiological measures, in line with views suggesting introspective access to cognitive-affective processes may be at least partly limited (Mikulincer & Shaver, 2016). Inasmuch as physiological measures provide access to action *tendencies* (i.e., emotions) that are not necessarily enacted (Lang, Bradley, & Cuthbert, 1997), some aspects of generalization processes may be more readily detectable via physiological assessment. Physiological research also holds the promise of helping to further disentangle the constituent cognitive-affective processes underpinning representation-generalization, perhaps especially those involving partly automatic initial expectations and early processing of (negative) emotion (Bretherton & Munholland, 2016).

Physiological assessment in this area inevitably raises the issue of experimental situations under which to best elicit representation-generalization. Thus, scholars stress that generalization may be most evident in the absence of the caregiver and of considerable knowledge about others (Dykas & Cassidy, 2011; Sroufe, Egeland, Carlson, & Collins, 2005). Moreover—analogous to the role of distress in activating the attachment system in infants—attachment representations may exert their strongest effects in the context of interpersonal challenges (Ainsworth, 1990), such as social exclusion. Thus, preliminary work shows that adolescents with insecure-dismissing attachment respond to re-inclusion by unfamiliar peers following exclusion with elevations in a neural correlate of expectancy violation (N2) compared to their securely attached counterparts (White, Wu, Borelli, Mayes, & Crowley, 2013). Likewise, *during* peer exclusion attachment dismissal coincided with a neural correlate of more negative appraisal and less approach motivation (diminished left frontal slow-wave activity; White et al., 2012). Also, DeWall et al. (2012) found that during exclusion adult avoidant attachment predicts reduced activation in the dorsal anterior cingulate (dACC) and the anterior insula (AI), neural regions subserving expectancy violation, salience processing, conflict monitoring, or social pain (Eisenberger, 2015).

Notably, neuroscientists conceptualize dACC and AI activation during exclusion as an adaptive alarm or aversive teaching signal, alerting the individual when input deviates from a desired goal and requires action to be taken (Eisenberger, 2015). This view dovetails with data showing that exclusion-related activation in these areas predicts the degree to which individuals seek proximity after exclusion (Chester, DeWall, & Pond, 2016). Moreover, scholars posit that diminution of this alarm signal during exclusion—which has also emerged following exposure to early caregiver separation (Puetz et al., 2014)—may originate from chronic rejection experiences linked to insecure attachment relationships (Chester, Pond, Richman, & DeWall, 2012).

Besides the effects of attachment, scholars have examined whether physiological responses to exclusion vary as a function of social skills and peer relationships. For example, in accordance with the aforementioned patterns, in two studies with adolescents less social competence and lower peer acceptance predicted decreased activation in dACC and AI during exclusion (de Water et al., 2017; Masten et al., 2009). This may map onto findings indicating that bullying and peer-victimization is linked to blunted cortisol and physiological responses (e.g., vagal withdrawal) to social exclusion and psychosocial stressors (Sijtsema, Shoulberg, & Murray-Close, 2011). However, data in this area are somewhat inconsistent regarding the direction of effects and have also revealed positive associations between peer-rejection and -victimization and more pronounced dACC and AI activation and vagal withdrawal (e.g., Rudolph, Miernicki, Troop-Gordon, Davis, & Telzer, 2016; Sijtsema et al., 2011). Despite these inconsistencies, owing to links to attachment representations and real-world peer relations, exclusion may qualify as a potential experimental situation to examine processes of representation generalization in real-time. Yet, to date, studies bridging these domains in children are lacking and physiological research in this area is still in its infancy, drawing on relatively small samples of adolescents or adults, that is, long after generalization of attachment patterns first emerges in development (see Groh et al., 2014). This study aims to begin closing these fundamental gaps by testing an indirect pathway emanating from preschoolers' parent representations through physiological reactivity during social exclusion to school-age peer relationships.

As a physiological measure, we opted for event-related transient cardiac slowing. Assessment of transient cardiac slowing capitalizes on a fast-acting vagus that outstrips sympathetic innervation of the heart by up to 2 s, placing it under sole parasympathetic influence (Berntson, Cacioppo, & Quigley, 1993). Cardiac slowing occurs when stimuli signal negative outcomes (e.g., error feedback), depart from the current mental set (e.g., high novelty), or violate expectancies, reflecting part of an orienting response involving inhibition of behavior, elevated attention, and processing of (performance-relevant) feedback, paving the way to more effective responding (Bradley, 2009; van der Molen, 2000). Among children, cardiac slowing occurs under similar conditions (see van der Molen, 2000), including exposure to unexpected negative feedback, though it has proven less sensitive to feedback incorporation for future performance (Crone, Somsen, Zanolie, & van der Molen, 2006).

In several recent studies, cardiac slowing was linked to social rejection vis-à-vis acceptance and nonsocial feedback, especially when rejection was unexpected (Gunther Moor, Bos, Crone, & van der Molen, 2014; Gunther Moor, Crone, & van der Molen, 2010; van der Veen, Burdzina, & Langeslag, 2019; van der Veen, van der Molen, Sahibdin, & Franken, 2014). Notably, developmental work shows increased cardiac slowing to unexpected peer rejection for adolescents versus children, particularly among females (Gunther Moor et al., 2014). Furthermore, individual difference work in adults shows that neuroticism predicts blunted cardiac slowing when acceptance was expected and followed by (unexpected) rejection or actual acceptance (as expected; van der Veen, van der Molen, van der Molen, & Franken, 2016). Across studies, a prevailing model suggests that cardiac slowing reflects engagement of the aforementioned neural alarm signal in response to exclusion (Gunther Moor et al., 2010; van der Veen et al., 2014, 2016, 2019). The neural alarm signal view is further bolstered by the finding that activation of the dACC specifically coincides with unexpected versus expected rejection in neuroimaging studies using the same social judgment task and the known role of dACC and AI in mediating parasympathetic innervation and slowing of the heart (see Gunther Moor et al., 2010; van der Molen, 2000).

The Present Study

Building on exploratory work on attachment representations and neural correlates of exclusion in older youth (e.g., White et al., 2012, 2013), this study took a confirmatory approach in a sizable sample (N = 165). We collected heart-rate using an electrocardiogram (EKG) as the study's sole physiological measure, targeting one of the earliest periods when generalization of representations may be particularly salient, that is, the preschool to school-age transition which is accompanied by growing investment in peers (Sroufe et al., 2005). Crucially, during this transition children are commonly faced with a new set of peers with whom they have limited experience—potentially fostering a situation where they rely more heavily on their internal representations of caregivers for guidance. Moreover, consistent with stronger meta-analytic effects of attachment on peer competence relative to internalizing symptoms (Groh et al., 2017) as well as the notion attachment representations are thought to affect processing and behavior within interpersonal relationships (Thompson, 2016), we explored whether the mediation is *specific* to emerging peer problems or also applies to emotional symptoms, which have also shown associations with neural responses to social exclusion (e.g., Rudolph et al., 2016).

Extending insights about cardiac slowing and social expectations, we postulated that positive attachment-related representations may nurture a positive expectancy of social inclusion (Thompson, 2016). Events that signal negative social outcomes, such as exclusion, would violate this expectancy triggering cardiac slowing. Accordingly, we predicted that children with more positive parent representations would generalize these to the laboratory, responding to social exclusion-related trials with greater cardiac deceleration relative to identical trials during social inclusion. To show that these representations indeed generalize to the peer domain, we predicted that exclusion-related cardiac slowing will meet the criteria for a mediator between preschool parent representations and school-age peer problems.

Method

Sample

This study reports on 165 children (46.1% female), predominantly of European Caucasian descent (91.2%, 8.8% mixed, Asian, Hispanic) and middle-class background (see Table 1), all of whom completed a physiological assessment at early school-age (8.42 years; SD = 2.7 months) between January, 2014 and April, 2015. Of these children, n = 139 also participated in a first visit at preschool-age (5.19 years; SD = 5.9 months) between February, 2010 and January, 2012. Children in this study were a subsample of a larger longitudinal study comprising N = 304 children, of whom n = 272 and n = 249 participated in the preschool and school-age visits, respectively (see Klein et al., 2019 for details). Of the latter, n = 179 children took part in the physiological assessment reported here (14 children with incomplete or poor quality EKG datasets excluded). To increase the sample's saturation with risk, children were oversampled for emotional symptoms using the Strengths and Difficulties Questionnaire (SDQ; Goodman, 1997; see below). To this end, caregivers of 1,738 three- to five-year-olds from the Leipzig catchment area, a large city in eastern Germany, completed the SDQ which was used to identify 304 children scoring above (n = 119; 39.1%) or below (n = 185; 60.9%) the borderline cut-off on emotional symptoms at preschool or early school-age.

Table 1
Demographic Information on the Longitudinal Sample and the Subsample With Physiological Assessments Participating in This Study

	Total sample N = 304		Subsample N = 165	
	n	(%)	n	(%)
Females	149	(49.0%)	76	(46.1%)
Maternal education				
Lower secondary or lower	22	(7.2%)	9	(8.2%)
Upper secondary	104	(34.2%)	54	(32.7%)
High school diploma	49	(16.1%)	30	(18.2%)
University	124	(40.8%)	69	(41.8%)
Missing	5	(1.6%)	3	(1.8%)
Monthly household income				
Low (<2,000€)	84	(27.6%)	40	(24.2%)
Medium (2,000€–< 6,000€)	193	(63.5%)	110	(66.7%)
High (>6,000€)	10	(3.3%)	5	(3.0%)
Missing	17	(5.6%)	10	(6.1%)
Domestic situation				
Lives with both parents	224	(73.7%)	128	(77.6%)
Lives with one parent	65	(21.4%)	31	(18.8%)
Other or missing	15	(4.9%)	6	(3.6%)

The subsample with sufficient physiological data were comparable to the remaining sample in terms of gender, age, peer problems and emotional symptoms, monthly household income, parental education, and the domestic situation (living with both vs. not with both parents) at the preschool and school-age assessments (all ps > .09). For the present subsample, the four-band solution for the SDQ yielded the following percentages for the "close to average range," typically encompassing 80% of community children (sdqinfo.com, 2017): For emotional symptoms, teachers and parents agreed that 46.8% and 57.6% of children were in the "close to average" range for the preschool and school-age assessments, respectively. For peer problems, teachers and parents agreed that 74.1% and 73.6% of children were in the "close to average" range for the preschool and school-age assessments, respectively.

Measures

Parent Representations in Child Narratives

To assess children's positive parent representations, children were asked to complete eight standardized story-beginnings ("stems") from the MacArthur Story Stem Battery (MSSB; Emde, Wolf, & Oppenheim, 2003). The MSSB is a valid and reliable narrative measure of internal representations of 3- to 8-year-olds (see Emde et al., 2003; Yuval-Adler & Oppenheim, 2014). The experimenter narrated each stem with the help of Duplo® dolls, culminating in a socioemotional challenge. At this point, the child was encouraged by experimenters to show and tell what happens next. The set of dolls varied with each stem, but the child protagonist (gender-matched to participants), and a parent figure featured in every stem. After introducing the dolls to the child, the experimenter started with a warm-up story about the child protagonist's birthday, which was not coded. The warm-up story aimed to acclimatize children to the procedure and reduce potential inhibitions as well as promoting rapport with the experimenter. Following this, experimenters continued with a fixed order of stems, using scripted probes, if necessary, to clarify story-elements or re-engage the child. The stems used in this study aimed to cover three broad interpersonal themes, echoing children's everyday life: (a) distress (i.e., child injury, parents arguing over lost keys, child afraid while alone in bed at night), (b) moral dilemmas (loyalty toward friend vs. empathy toward mother or sibling, obedience to parent vs. empathy toward sibling), and (c) separation (loss of and reunion with pet dog, exclusion from parental relationship).

Videos of the ~40-min MSSB assessment were coded by independent trained raters following the MacArthur Narrative Coding Manual (Robinson, Mantz-Simmons, Macfie, Kelsay, & The MacArthur Narrative Group, 2002). To the extent that cardiac slowing has proven sensitive to rejection, especially when it occurs unexpectedly, positive portrayals of parent characters (positive parent representations) struck us as the candidate dimension that might be correlated with cardiac slowing during exclusion, reflecting the degree to which exclusion violates expectancies. Nevertheless, in an exploratory fashion and partly due to previous findings in youth regarding effects of attachment dismissal on neural responses to exclusion (e.g., White et al., 2012), we also decided to consider denial and negative parent representations as additional manifest variables in our analyses.

Positive parent representations involve protective, caretaking, affectionate, and helpful behavior by the parent character in the narrative (e.g., parent compliments or helps the child). Negative parent representations involve harsh, punitive, rejecting and ineffectual behaviors of the parent character in the narrative (e.g., parent aggresses against the child or pushes child away saying "That's not a proper wound".). Positive and negative mother and father portrayals were coded separately as present ("1") or absent ("0") for each story. Denial reflects the degree to which children ignore the key challenge presented in the story stem, coded as 0 (children deal with the key issue of their own accord), 1 (children deal with the key issue in the stem, but only after being prompted), 2 (children fail to address the key issues, even after prompting). According to Cicchetti's (1994) criteria, the inter-rater reliability for positive and negative mother and father representations and denial was in the good to excellent range ($ICC_{pos\ mother} = .89$; $ICC_{pos\ father} = .65$; $ICC_{neg\ mother} = .80$; $ICC_{neg\ father} = .60$; $ICC_{denial} = .85$), respectively (double-coding of 10% of children ($n = 25$) in the full sample who provided story-completions ($n = 250$) at preschool age). Average mother and average father representation codes were combined to a single mean score for each story (correlations between mother and father representations: $r_{pos} = .60$, $p < .001$, and $r_{neg} = .363$, $p < .001$). Previously, positive portrayals of parent characters in story-completion measures have proven positively associated with observations of secure attachment in infancy (Sher-Censor & Oppenheim, 2004), parental supportiveness (Belden, Sullivan, & Luby, 2007), parental sensitivity (Murray, Woolgar, Briers, & Hipwell, 1999), and with parent- or teacher-reported child prosociality (Stadelmann et al., 2007), remediable by attachment-based interventions (Toth, Maughan, Manly, Spagnola, & Cicchetti, 2002), as well as inversely associated with parental distress (Oppenheim et al., 1997), and child antisocial behavior (Oppenheim et al., 1997; Page & Bretherton, 2001). To estimate latent positive parent representations, we averaged scores on positive parent representations across the stories belonging to each of the three interpersonal themes mentioned above, which were then modeled as the manifest indicators.

Peer Problems and Emotional Symptoms

At preschool and school-age, parents and teachers reported on emotional symptoms and peer problems using the Emotional Symptoms and Peer Problems subscales of the SDQ (Goodman, 1997). To create multi-informant composite scores, we initially averaged across parent and teacher items and then created three item-parcels for each subscale (see Supporting Information for details). Correlations between parent and teacher reports were as follows: for peer problems at preschool-age, $r(132) = .322$, $p = .001$, and school-age, $r(137) = .291$, $p < .001$, for emotional problems at preschool-age, $r(132) = .207$, $p = .016$, and school-age, $r(137) = .287$, $p = .001$. Our strategy was informed by Kraemer et al.'s (2003) multi-informant approach which takes low to moderate agreement between informants into account, arguing that the degree to which they converge reflects the trait dimension of the child. In line with this, we opted for aggregating scores across informants which approximates the convergence factor outlined by Kraemer and colleagues (see Malti, Perren, & Buchmann, 2010).

Covariates

Verbal Competence

Because verbal competence has often been found to be associated with representational indices in narratives (Oppenheim et al., 1997), we included a validated preschool verbal competence measure (Elben & Lohaus, 2000) in our study.

Sociodemographic Variables

Gender (0 = female, 1 = male) and socioeconomic status, estimated as a latent variable based on education of mother and father as well as household income (labeled s1–s3), served as further covariates.

Cyberball Experiment

Children played a virtual ball-toss game ("Cyberball"; Williams, Cheung, & Choi, 2000) ostensibly with two age- and gender-matched coplayers over the Internet whose names and photographs were displayed on the screen. Unbeknownst to participants, coplayers were computer-generated and preprogrammed to initially play fair ("inclusion"), then unfair ("exclusion"). Inclusion was comprised of 10 "my-turn" events (participant receives ball), 10 "throw" events (participant throws ball), and 10 "not-my-turn" events (coplayers pass to one another). After five consecutive ball-tosses between the coplayers, the exclusion phase commenced, comprised of 35 "rejection" events wherein the participant did not receive the ball (outwardly identical to not-my-turn events) interspersed with three my-turn events and three participant throws (to sustain attention). The first not-my-turn event during inclusion and the first events following each my-turn event during exclusion were omitted from analyses to minimize the influence of novelty in the stimulus sequence on cardiac slowing. The version of Cyberball used here resembled the child-friendly paradigm designed by Crowley, Wu, Molfese, and Mayes (2010) that takes a number of measures to enhance the engagement and credibility of the deception. Children were thus initially guided through a fake Google® Link to a screen showing them that the game was loading. Next, participants were apparently connected over the Internet to eight other children whose photos appeared sequentially in two rows displayed on the screen (photos of children's neutral faces were retrieved from the NIMH-ChEFS picture bank; Egger et al., 2011). To ostensibly select the child who would get to choose their coplayers, participants completed a brief coin-flip-like procedure called "spin the dial" which was rigged so that participants would always win. Using a mouse, participants chose with whom they would like to play. Next, children were asked to indicate which of six baseball gloves they would like to use during the game. Finally, they were informed about the controls of the game. Children played with game-pads fitted with a red and blue button that matched the colors of names of their coplayers to ease understanding of the game-controls.

To assess cardiac slowing, we adapted an event-related version of Cyberball, which superimposes static events on the dynamic Cyberball paradigm (Crowley et al., 2010). To this end, the ball briefly vanished before each ball-pass (1,000 ms) and then reappeared en route to the next player, remaining static for 1,500 ms before traveling to the next player who caught the ball and kept it in his glove for 1,000–2,000 ms (random jitter). Events were locked to the reappearance of the ball, which sent an event-marker to the EKG recording software and was used as the event-onset. Compared to previous work, baseline inclusion was abbreviated to account for the risk of disengagement among young children. For ethical reasons, our assessment also included a final round of Cyberball involving over-inclusion during which children were included 86% of the time by a new set of players. Our intention was to provide children with a uniformly positive closing experience after the social stress of exclusion, as positive experiences are considered more effective with young children than a formal debriefing procedure, which can erode the trust in experimenters (Thompson, 1990).

EKG Data Collection and Preprocessing

Cardiac data during Cyberball were collected using a 3-Channel wireless electrocardiogram (EKG; BioNomadix System by Biopac®, Biopac Systems, Goleta, CA, USA). EKG waves were directly displayed on a second computer screen, to allow for online data-quality check. If necessary, abrasive pads were applied to promote signal conduction before placing three electrodes on the child's chest in accordance with Einthoven's triangle. EKG data were digitized at a sampling rate of 1,000 Hz. All EKG data were inspected individually, and artifact detection and correction were performed using ARTiiFACT (Kaufmann, Sütterlin, Schulz, & Vögele, 2011), interpolating interbeat intervals (IBIs) with a cubic spline function in the event of unidentifiable R-spikes (applied to <5% of IBIs).

As an index of cardiac slowing, heart rate (HR) change for 4,000 ms postrejection and post–not-my-turn events was extracted in Matlab® using the mean HR across the 2 s prior to each event as a reference. Outliers $\pm$ 3 *SD*s from mean HR change were winsorized. In line with the aforementioned transient parasympathetic dominance (Berntson et al., 1993), the analyses focused on 2,000 ms of post-event HR change for each event-type, segmented into five 400 ms epochs of mean HR change. Events were combined into three parcels that served as manifest indicators for latent cardiac slowing to not-my-turn and rejection events (for details on parcelling, see Supporting Information and Table S3).

Data-Analyses

To test our hypotheses we used structural equation modeling in Mplus 7.3 (Muthén & Muthén, 2012) with full information maximum likelihood estimation of missing data. We specified a second-order latent difference score (LDS) to model physiological reactivity (see Burt & Obradović, 2013) as a change in average event-related cardiac slowing between experimental (rejection) and baseline (not-my-turn) events. To model latent constructs of cardiac slowing, peer problems, and emotional symptoms, we used a parcelling approach (for additional details, see Supporting Information). In constructing our measurement models we followed the guidelines by Little (2013), whereby a latent factor should be just identified, which is the case when there are three indicators for each latent factor (or multiples of three). This strategy avoids artificially inflating model fit indices, which occurs when using more than three indicators per latent variable, that is, when there are unnecessary degrees of freedom (Little, 2013). *R* was used to create Figures 1 and 3 to display cardiac slowing using estimated marginal means, derived from GLM analyses.

Following preliminary analyses involving checks of fit indices of measurement models, measurement invariance, and the validity of the exclusion manipulation, we estimated three models. First, we sought to confirm that preschool positive parent representations predicted LDS cardiac slowing. In the second model, we included peer problems in our analysis. As a preliminary analysis for this model, we computed the effect of positive parent representations on preschool peer problems and on school-age peer problems. Then, we tested an indirect path from preschool positive parent representations via LDS cardiac slowing to school-age peer problems while accounting for preschool peer problems. In the third model, we included school-age emotional symptoms in our analysis and tested an indirect path from preschool positive parent representations via LDS cardiac slowing to school-age emotional symptoms while accounting for preschool emotional symptoms. For each of these models, we initially performed the analysis without covariates before testing whether effects were robust to covariate adjustments. Mediation effects were modeled separately using 1,000 unstandardized bias-corrected bootstrap intervals.

Results

Preliminary Analyses

A set of preliminary analyses showed that the model fit of the individual measurement models of our latent variables were uniformly good (Table S4 displays % missing, means, *SD* and range of indicators; Table S5 shows individual measurement models; Table S6 displays intercorrelations between indicators). Using Crayen's (2010) Chi-square Difference Calculator (CDC) we found that the models

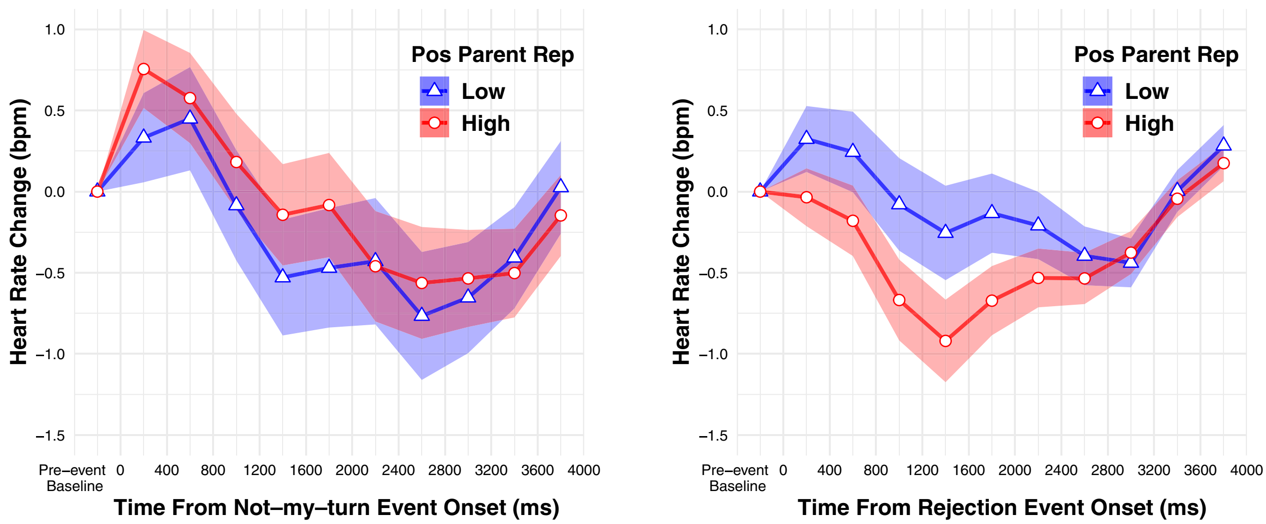

Figure 1. Grand-average heart-rate change for (a) not-my-turn events (not receiving ball during inclusion; left panel) and (b) rejection events (not receiving ball during exclusion; right panel) for children with low and high positive parent representations (median split), controlling for parent education, gender, and verbal competence. Lower values on heart rate (HR) change indicate greater cardiac slowing. Values displayed with standard errors and referenced to mean pre-event baseline HR.

with constrained factor loadings for both timepoints showed comparable fit relative to models without constraints for emotional symptoms (Difference in $\chi^2 = 0.44$, $df = 2$, $p = .803$) and peer problems (Difference in $\chi^2 = 4.45$, $df = 2$, $p = .108$), consistent with metric measurement invariance.

To test for scalar invariance using CDC, models with and without constrained intercepts were compared. Both for emotional symptoms and for peer problems comparisons indicated that the models with fewer constraints showed superior fit (Emotional symptoms: Difference in $\chi2 = 9.187$, $df = 3$, $p = .027$; Peer problems: Difference in $\chi2 = 10.201$, $df = 3$, $p = .017$), inconsistent with scalar measurement invariance. However, partial scalar measurement invariance was obtained (Difference in $\chi^2 = 1.183$, $df = 2$, $p = .553$) after releasing the constraint on the second item parcel (P1b, P2b) for peer problems, containing those items of the scale related to group processes (SDQ Item 14: Generally liked by other children and SDQ Item 19: Picked on or bulled by other children), consistent with the notion that group processes may undergo important developments between preschool and school-age (Monks, 2011). Likewise, partial scalar measurement invariance was obtained for emotional symptoms (Difference in $\chi^2 = 3.051$, $df = 2$, $p = .218$) after releasing the constraint on the third indicator (E1c, E2c), reflecting worries (SDQ Item 8: Many worries), which is consistent with the idea that worries (e.g., about the future) may require a certain level of cognitive maturity to arise (Muris & Field, 2011). In light of this, it is important to interpret prospective findings with greater caution, that is, not in terms of a simple increase or decrease in peer problems or emotional symptoms from preschool to school-age.

Moreover, we also aimed to check that our exclusion manipulation worked, in the sense of rejection events actually inducing more pronounced cardiac slowing compared to not-my-turn events. Given that children in this study were oversampled for emotional symptoms, we decided to exclude children with high and very high emotional symptoms at school-age ($n = 17$) for this preliminary analysis. In the remaining sample of 148 children, we included a difference score in our latent change model for cardiac slowing (all other variables excluded). The model primarily yielded a good fit (root mean square error of approximation [RMSEA] = .086, comparative fit index [CFI] = .993, standardized root mean squared residual [SRMR] = .029) showing that rejection events induced significantly greater cardiac slowing ($M = -.467$; $SE = .127$) compared to not-my-turn events ($M = .055$; $SE = .188$), Unstandardized $B = .522$, $p = .010$, Cohen's $d_{RM} = -.220$.

Main Analyses

Model 1 indicated good fit to the data (RMSEA = .049; CFI = .993; SRMR = .035), showing that preschool positive parent representations predicted latent change (LDS) in cardiac slowing from not-my-turn to rejection (β = −.349, p < .001). Upon including negative parent representations and denial, the model fit remained adequate (RMSEA = .069, CFI = .979; SRMR = .070) and the path from positive parent representations to LDS cardiac slowing remained highly significant (β = −.359, p < .001), whereas the paths for negative parent representations (β = .071, p = .211) and denial (β = −.014, p = .811) to LDS cardiac slowing were nonsignificant. The model including covariate adjustments (gender, preschool verbal competence, SES) yielded adequate fit (RMSEA = .062; CFI = .974; SRMR = .068; see Supporting Information for details), confirming an effect of positive parent representations on cardiac slowing (β = −.315, p = .002). Figure 1 illustrates how children high on positive parent representations show enhanced cardiac slowing to rejection events (not receiving ball during exclusion) compared to children low on positive parent representations, while no such effect emerged for not-my-turn events (not receiving ball during inclusion).

In Model 2, we added school-age peer problems to the analysis. Preliminary analyses indicated that positive parent representations coincided with lower preschool peer problems (β = −.359; p = .002; RMSEA = .000; CFI = 1.00; SRMR = .025), but not lower school-age peer problems (β = −.016, p = .902; RMSEA = .043; CFI = .979; SRMR = .042). The initial model indicated good fit to the data (RMSEA = .000; CFI = 1.000; SRMR = .046), supporting a significant path from cardiac slowing to peer problems (β = .268, p = .009), and suggesting that positive parent representations exerted an indirect effect on school-age peer problems via LDS cardiac slowing (95% CI [−1.417, −.014]). Figure 2 displays the model including covariates (gender, preschool verbal competence, SES), also yielding good model fit (RMSEA = .043; CFI = .974; SRMR = .065), a significant path from cardiac slowing to peer problems (β = .295, p = .003), and an indirect effect (95% CI [−1.416, −.011]; see Table 2

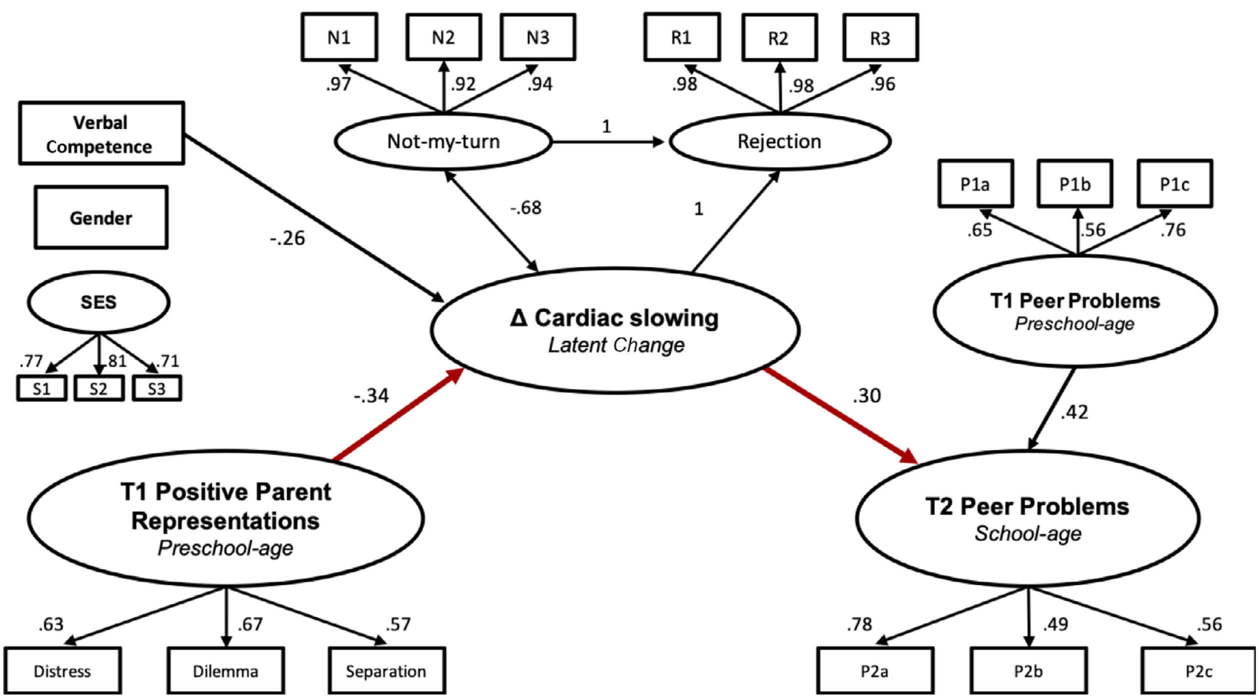

Figure 2. Structural equation modeling supported a simple mediation (red arrows) from preschool positive parent representations via cardiac deceleration to peer problems. Gender, SES, and verbal competence are controlled. Significant paths, factor loadings, and the second-order latent change model for cardiac slowing are displayed.

Note. N1–N3 = indicators for not-my-turn (Parcels: N1 = 0–400 ms with 1,200–1,600 ms; N2 = 400–800 ms with 1,600–2,000 ms; N3 = 800–1,200 ms); R1–R3 = indicators for rejection (Parcels: R1 = 0–400 ms with 1,200–1,600 ms; R2 = 400–800 ms with 1,600–2,000 ms; R3 = 800–1,200 ms); P1a–P1c = indicators for preschool peer problems (Parcels: P1a: item 11 and 23, P1b = items 14 and 19, P1c = item 6); P2a–P2c = indicators of school-age peer problems (Parcels: P2a: item 11 and 23, P2b = items 14 and 19, P2c = item 6); SES = socioeconomic status; S1–S3 = indicators for socioeconomic status (S1 = maternal education, S2 = paternal education, S3 = monthly household income).

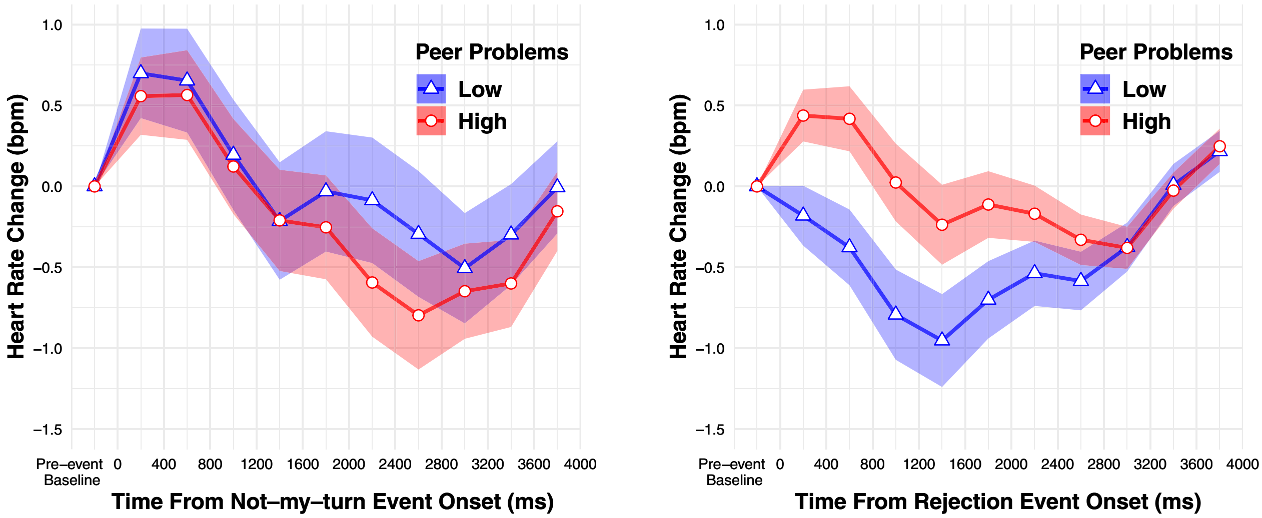

Figure 3. Grand-average heart rate change for (a) not-my-turn events (not receiving the ball during inclusion; left panel) and (b) rejection events (not receiving the ball during exclusion; right panel) for children with low and high peer problems (median split), controlling for gender, parent education, verbal competence. Lower values on heart rate change indicate greater cardiac slowing. Values displayed with standard errors and referenced to mean pre-event baseline heart rate.

for all coefficients). Figure 3 juxtaposes cardiac slowing to not-my-turn events and rejection events as a function of peer problems. To confirm the robustness of these effects across informants we conducted several additional analyses with disaggregated parent and teacher ratings which yielded comparable effects (see Supporting Information).

In Model 3, emotional symptoms rather than peer problems were considered as the outcome in the analysis. The initial model without covariates indicated good fit to the data (RMSEA = .040; CFI = .988; SRMR = .050), but no support for a path from cardiac slowing to emotional symptoms ($\beta = .073$, $p = .450$), nor for an indirect path from parent representations via cardiac slowing to school-age emotional symptoms (95% CI [−.789, .212]). The model including covariates (gender, preschool verbal competence, SES) yielded good fit (RMSEA = .054; CFI = .963; SRMR = .069), but, again, no support for a path from cardiac slowing to emotional symptoms ($\beta = .069$, $p = .526$), nor for an indirect path from parent representations via cardiac slowing to school-age emotional symptoms (95% CI [−.682, .253]).

Discussion

In recent years, scholarship has confirmed a robust link between children's parent–child attachment and subsequent peer relations. However, the mechanism underpinning this link has continued to be a source of speculation (e.g., Elicker et al., 1992; Groh et al., 2014). Our study provides physiological evidence consistent with some of these speculations, but may also point in novel directions. We found that children who portray parents as effective and helpful (positive parent representations) in a widely used narrative task at preschool-age responded to exclusion-related relative to outwardly identical inclusion-related trials in Cyberball with greater cardiac slowing—a known physiological correlate of rejection. In turn, exclusion-related cardiac slowing served as a mediator of the putative protective influence of preschool positive parent representations on school-age peer problems.

In the context of social exclusion, researchers have drawn parallels between cardiac slowing and a neural alarm signal that calls attention to deviations from desired goals, motivating individuals to take action to address the source of the deviation (Gunther Moor et al., 2010; van der Veen et al., 2019). Analogously, cardiac slowing occurs when events convey negative information, such as negative feedback or punishment, offsetting automatic processing, and inhibiting behavior (van der Molen, 2000). A potentially useful umbrella concept to understand the meaning of cardiac slowing during exclusion may be orienting, involving processing information on identity (and intent) of (animate) stimuli ("What is that?") as well as attendant preparation for a rapid and effective response ("What should I do?"; see Bradley, 2009). Inasmuch as brief bouts of exclusion are common events, effective

Table 2

Standardized β-Coefficients Summarizing Regression (→) and Correlational Paths (↔) in Model 1 (Prediction of Cardiac Slowing), Model 2 (Mediation Model With Peer Problems as Outcome), and Model 3 (Mediation Model With Emotional Symptoms as Outcome), Including Covariate Adjustments

	Model 1	Model 2	Model 3
Predictors of cardiac slowing			
Preschool pos parent → slowing	−.315**	−.342***	−.316**
SES → slowing	.091	.044	.087
Preschool verbal comp → slowing	−.266**	−.262**	−.265**
Gender → slowing	.027	.025	.027
Predictors of school-age peer problems			
Slowing → school peer probs	—	.295**	—
SES → school peer probs	—	−.220	—
Preschool peer probs → school peer probs	—	.422**	—
Preschool pos parent → school peer probs	—	.272	—
Preschool verbal comp → school peer probs	—	.151	—
Gender → school peer probs	—	−.017	—
Predictors of school-age emotional symptoms			
Slowing → school emotional syms	—	—	.062
SES → school emotional syms	—	—	−.159
Preschool emotional syms → school emotional syms	—	—	.289**
Preschool pos parent → school emotional syms	—	—	−.014
Preschool verbal comp → school emotional syms	—	—	−.025
Gender → school emotional syms	—	—	−.047
Associations between latent variables			
Slowing ↔ not-my-turn	−.692***	−.681***	−.693***
Preschool pos parent ↔ not-my-turn	.221*	.253*	.221*
Preschool peer probs ↔ not-my-turn	—	−.044	—
Preschool pos parent ↔ preschool peer probs	—	−.384***	—
Preschool emotional syms ↔ not-my-turn	—	—	.047
Preschool pos parent ↔ preschool emotional syms	—	—	−.052
Associations between covariates			
SES ↔ not-my-turn	.080	.078	.079
SES ↔ preschool pos parent	−.108	−.112	−.110
Preschool verbal comp ↔ not-my-turn	.236**	.236**	.236**
Preschool verbal comp ↔ preschool pos parent	.041	.040	.041
Preschool verbal comp ↔ SES	.481***	.478***	.477***
SES ↔ preschool peer probs	—	−.295**	—
Preschool verbal comp ↔ preschool peer probs	—	−.254*	—
SES ↔ preschool emotional syms	—	—	−.147
Preschool verbal comp ↔ preschool emotional syms	—	—	.057

$^{*}p < .05$. $^{**}p < .01$. $^{***}p \leq .001$.

responses to such bouts aided by orienting may be crucial to prevent their recurrence and continuation. Consistent with other data in the field (Masten et al., 2009; de Water et al., 2017), a moderately sensitive and receptive alarm system may thus assist individuals in attending more closely to negative social stimuli which may, in turn, foster adaptive responses, accounting for more peer competence and fewer peer problems. That said, our findings are inconsistent with data showing that chronic peer rejection may also be associated with a hypersensitive neural alarm system response to exclusion (e.g., Rudolph et al., 2016), suggesting that mid-range psychophysiological responses may potentially be most adaptive.

Our data also carry implications about the developmental origins of physiological reactivity to exclusion in attachment representations. One possibility revolves around the notion that as attachment representations increasingly become "a property of the child" (Bowlby, 1988, p. 127), they come to provide the basis for expectations of others that go on to influence interactions, akin to cognitive-affective filters. Notably, ample findings show that cardiac slowing is more pronounced not simply for rejection per se, but only for rejection *after* participants explicitly indicate expecting acceptance (Gunther Moor et al., 2010; van der Veen et al., 2014, 2016). Independent of this rejection literature, cardiac slowing has a long tradition of being linked to expectancy violation, such as in response to oddball paradigms or highly novel stimuli (Lang et al., 1997). Viewed from this angle, our data could lead us to conclude that exclusion comes as a greater surprise for children with positive parent representations due to their cumulative experiences of reliably sensitive and responsive caregiving, giving rise to positive inclusionary expectations they carry forward into the novel encounters with unfamiliar others, an interpretation that concords with prior work (White et al., 2013).

However, recent data on rejection-related cardiac deceleration suggest that it can also occur during expected as well as unexpected rejection (van der Veen et al., 2019). Moreover, as mentioned above, cardiac slowing surfaces also for negative outcomes, irrespective of whether they are explicitly expected or not (Bradley, 2009). Viewed from this perspective, children with more positive parent representations may exhibit greater openness (or less inhibition) to process negative social information. Over the course of development, these children may have internalized a caregiver who is available and responsive in stressful situations, helping them to coregulate and process negative social information (Chester et al., 2012). Conversely, for those children with less positive internalizations, negative social information may pose a greater threat. Over time, children who continually experience caregivers who are under-responsive (e.g., due to feeling overtaxed) or rejecting of their bids, may eventually adapt via a blunted response to negative social information, potentially in an effort to minimize their reliance on caregivers for coregulation (Mikulincer & Shaver, 2016).

It is noteworthy that our results surfaced for positive parent representations, rather than denial or negative parent representations as indexed by our story-completion measure. Given that cardiac slowing has proven sensitive to rejection, especially when it occurs unexpectedly, we assumed from the outset that positive parent representations would provide a candidate correlate of cardiac slowing during exclusion, partly reflecting the degree to which exclusion violates expectancies generalized from these representations. Moreover, vis-à-vis other story-stem codes parent representations arguably afford a clearer demonstration of generalization. That is, as the MSSB includes multiple story-stems involving peers, siblings, or pets (Emde et al., 2003) codes such as denial may also be related to these characters, rather than to representations of caregivers per se. Using these codes to study the process of generalization of representations therefore may run a greater risk of conflating processes or representations related to caregivers and those already extrinsic to the child's attachment representations. Regarding the preferential link of cardiac slowing to positive, but not negative parent representations, this may be attributable to a stronger link between more positive (as opposed to less negative) representations and expectancy violation inherent in social exclusion. However, lower variance may have also played a role, given that roughly two-thirds of the sample showed no instance of negative parent representations. Future work should also consider whether avoidant, resistant and disorganized attachment strategies are associated with unique physiological responses to peer rejection.

A notable feature of our findings is that they accounted for peer problems at preschool-age. That said, peer problems at preschool and school-age were only partially measurement invariant, indicating that we were controlling for a related though not a commensurate latent construct at preschool-age and some aspects of the peer context (e.g., group processes) may differ qualitatively at school-age (Monks, 2011). Nevertheless, our data are in keeping with an indirect *prospective* effect of preschoolers' parent representations via cardiac slowing on school-age peer problems, independent also of potential stability of peer problems across this transition. This suggests that the indirect effect is likely to emanate from parent representations and bring about changes in peer problems, not vice versa. Moreover, neither sociodemographic variables nor preschool verbal competence explained the effect on cardiac slowing. Finally, in an additional exploratory step, we found that this effect was *specific* to school-age peer problems as opposed to school-age emotional symptoms, which showed no direct association with exclusion-related cardiac deceleration. This pattern may be related to the stronger effects of attachment on social competence than internalizing symptoms (Groh et al., 2017). At the same time, we focused on the autonomic nervous system, whereas neuroimaging data show associations between internalizing symptoms and exclusion responses at the neural level (e.g., Rudolph et al., 2016). However, this work has also predominantly focused on late childhood and adolescence, stages during which internalizing symptoms peak, and other patterns may emerge earlier in development.

Interestingly, we observed a mediation effect via cardiac slowing in the absence of a total effect of preschoolers' parent representations on school-age peer problems. We found a robust association between higher positive parent representations and fewer *preschool* peer problems. Although meta-analyses show robust links between attachment patterns and peer relations (Groh et al., 2014), other work, specifically on the preschool to school-age transition, has also failed to detect prospective effects, only showing effects when both constructs were measured contemporaneously, as we did here (Cassidy, Kirsh, Scolton, & Parke, 1996). Potentially, the major transition to school, in some cases, may lead to discontinuity and a mismatch between internal representations and the new peer environment, which may be better or worse than expected. While our results indicate that internal representations act on evolving peer relationships via expectancies that children carry forward into new interactions, various environmental factors may diminish the overall effect of parent representations on peer relations while leaving the indirect path intact (for statistical rationale, see Hayes, 2013). For example, more adverse environmental conditions are conceivable under which positive caregiver or secure attachment representations do not necessarily confer advantages (see Ein-Dor, Mikulincer, Doron, & Shaver, 2010).

More broadly, our results beg the overarching question, what conditions facilitate generalization of attachment-related representations. Our data suggest that social exclusion may provide such a context. Moreover, our results converge with findings in early adolescence showing, for instance, that insecure-dismissing attachment predicts a neural correlate of expectancy violation upon receiving the ball again during renewed inclusion following the Cyberball exclusion phase (White et al., 2013). Broadly speaking, the current data and the early adolescent study dovetail with the idea that attachment-related expectations are generalized primarily when individuals encounter or recover from threats of social disconnection (Ainsworth, 1990). Interestingly, this idea also maps onto the importance of activating the attachment system (e.g., via separation from the caregiver) in infancy in order to observe differences in attachment patterns (Ainsworth, Blehar, Waters, & Wall, 1978). Threats of social disconnection may serve as potent triggers for children's attachment-related representations of how "unwanted" they feel when distressed (Johnson et al., 2007). Generalization of representations may thus occur when children feel others will act analogously to caregivers either responding to or thwarting their interpersonal needs under threat.

Besides context, familiarity of the party with whom individuals interact has long been considered a key factor contributing to generalization. As such, recent meta-analytic evidence suggests that attachment influences are stronger for nonfriends versus friends (Groh et al., 2014). In a similar vein, the effects of positive parent representations on cardiac slowing in our study were observed during interactions with unfamiliar peers. Given that exclusion by friends versus nonfriends coincides with a differential neural signature (Baddam et al., 2016), the effects of representations in these contexts likely differ. Potentially, as individuals get to know one another more closely they may eventually form new internal representations of the specific relationship that may override the effects of attachment representations (Dykas & Cassidy, 2011)—a hypothesis that should be tested in future research.

A number of strengths and limitations of our study deserve consideration. First, ours is one of the first longitudinal studies to gain purchase on a physiological substrate of the process whereby attachment representations are generalized to future relationships in a sizable sample across the critical preschool to school-age transition. Second, we used a combination of age-appropriate multi-informant (parent and teacher reports) and multi-method assessments, including a rigorous experimental and event-related assessment to tap into children's expectancies during an interaction with unfamiliar peers.

Turning to the limitations, it should first be emphasized that causal inferences are unwarranted given the nonexperimental nature of our study, although assessment of parent representations preceded physiological data collection. In a similar vein, temperamental characteristics are known to predict rejection responses in Cyberball (Walker, Henderson, Degnan, Penela, & Fox, 2014) and could therefore interact with attachment to predict multiple outcomes. Hence, future work should aim to explore the potential interplay of temperament and attachment in the prediction of exclusion responses.

Second, the use of cardiac slowing is a relatively recent development within the exclusion literature. Notably, cardiac slowing has previously been detected for unexpected rejection feedback within social judgment tasks involving equal levels of alternating acceptance and rejection feedback from peers (e.g., Gunther Moor et al., 2010). As outlined earlier, for the present purposes we deemed Cyberball more appropriate, given that it exposes children to a prolonged exclusion *phase* (involving consecutive rejection events that occur repeatedly), with social uncertainty (in the social judgment task rejection events are clear), in turn, leaving more room for interpretation and thus, perhaps, for individual differences to take effect. Cyberball reliably induces moderate distress across a wide age-range (Abrams, Weick, Thomas, Colbe, & Franklin, 2011) and may thus function as a potent trigger for attachment representations to take effect (Ainsworth, 1990).

In sum, our study adds to a growing body of work on the physiological correlates of attachment processes (Long et al., 2020; White et al., 2020), offering novel insights into how generalization of working models may occur at an early age. More specifically, our data support the assumption that physiological correlates of rejection may offer a window into how children's internal representations of caregivers affect emerging peer relations. The fact that we detected evidence of mediation within a longitudinal design, independent of a range of covariate adjustments makes this finding especially appealing. It will be incumbent on future studies to assess the extent to which these or similar effects also extend to other developmental phases. Eventually, physiological studies hold the promise of helping to disentangle the component cognitive-affective processes underlying the generalization of attachment-related representations. Once those ingredients of representations that become generalized are unpacked they may prove particularly effective targets for interventions (see Toth et al., 2002) inasmuch as they determine continuity or discontinuity in relationships—for better or worse.

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Supporting Information

Additional supporting information may be found in the online version of this article at the publisher's website:

Appendix S1. Details on structural equation models and additional analyses.